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FIELD DEMONSTRATION OF MEMBRANE TECHNOLOGY FOR TREATMENT OF LANDFILL LEACHATE

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FIELD DEMONSTRATION OF MEMBRANE TECHNOLOGY FOR TREATMENT OF LANDFILL LEACHATE

Report prepared by:

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Abbreviations

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DI	Deionized
LMH or L/m^2/h	Litres per square meter of membrane area per hour
LPM	Litres per minute
MF	Microfiltration
RBC	Rotating Biological Contactor
RO	Reverse Osmosis
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TOX	Total Organic Halogen
TSS	Total Suspended Solids
UF	Ultrafiltration
USGFD or US gal/ft^2/d	US gallons per square foot of membrane per day
US gpm	US gal per minute

Glossary

Concentrate	-	Concentrated feed, or retentate, containing those substances which do not pass through the membrane.
Configured	-	In the same configuration used for full scale application (i.e. spiral module).
Flux	-	Rate of flow of permeate through an RO, UF or MF membrane per unit of membrane area (Reported in L/ m^2/ h (LMH) or US gal/ ft2/ d (US GFD).
Microfiltration	-	A cross-flow filtration process able to concentrate suspended solids and colloidal material.
Percent Recovery	-	Percentage of feed to a membrane process which is generated as treated permeate.
Permeate	-	Filtrate through a cross flow filtration membrane.
Permeate Rate	-	Rate of flow of permeate through a cross-flow filtration membrane (reported litres per minute (LPM)).
Refractory	-	Difficult to reduce or degrade.
Reverse Osmosis	-	A crossflow filtration process able to concentrate dissolved solids and ionic and organic material.
Salt Flux Test	-	A test to characterize an RO membrane using a standard solution of NaCl.
Stability Test	-	Experiment in which both the permeate and concentrate are returned for continuous processing feed.
Ultrafiltration	-	A cross-flow filtration process able to concentrate macromolecules and emulsified oils.
Volume Reduction	-	Percentage of feed to a membrane process which is generated as treated permeate.

1.0 EXECUTIVE SUMMARY

Landfill leachates commonly contain a wide spectrum of organic and inorganic contaminants which may pose a threat to surface or groundwater use. A variety of treatment processes have been considered and evaluated for the treatment of landfill leachates, including both physical/chemical and biological treatment processes. The objective of this study was to provide a technical and economic assessment of a membrane-based process for treatment of landfill leachate. The leachate under investigation contained high levels of iron and other metals, and relatively low levels of organics. A two-stage process incorporating precipitation/microfiltration to remove heavy metals and reverse osmosis to concentrate organics was developed and tested at pilot scale.

Results of the field testing program demonstrated that a precipitation/microfiltration and reverse osmosis (RO) process can be successful in achieving surface water quality and drinking water quality objectives for key inorganic parameters. Although there are no general guidelines for surface discharge quality in Ontario, the final permeate achieved effluent criteria for secondary sewage treatment plants for BOD and TSS, and was well below criteria for discharge to sewer. Overall process removals for key contaminants of concern were generally over 90%, at waste volume reductions of 75 - 80%.

The microfiltration (MF) field tests demonstrated stable flux rates ranging from 92 to 132 LMH (54 to 72 US gfd) can be maintained using leachate pretreated with lime alone or lime in combination with soda ash, even at volume reductions as high as 96%. Inorganic parameters were reduced from 50% to 99.9% by the precipitation/MF process. Following adjustment of the MF permeate to pH 6-7, an RO system obtained a stable flux of 32 LMH (19 US gfd) at volume reductions over 80%. The reverse osmosis process was successful in removing a high percentage of the organics present as measured by COD, BOD, and TOC, from the MF permeate.

The combination of lime pretreatment prior to microfiltration, and acidification prior to reverse osmosis is the most effective option for allowing RO volume reductions up to 75%. If RO volume reductions greater than 75% are required, lime pretreatment with addition of soda ash can be used in the MF to remove calcium and reduce calcium carbonate scale formation on the RO

membranes. Acidification of the MF permeate prior to the RO is needed to maximize overall system performance.

A comparison of the costs of the developed process with two alternative processes was conducted and indicated that the treatment process incorporating precipitation/MF for metals removal and reverse osmosis for organics removal was a cost-competitive option to conventional precipitation/clarification followed by biological treatment using a rotating biological contactor, for flowrates less than 55,000 litres per day (10 US gpm). A treatment process using conventional precipitation and reverse osmosis with recirculation of the RO concentrate was the least expensive of the three options considered, at $3.23 per 1,000 litres for a system treating 165,000 litres per day. This process should be considered for treatment of relatively low strength leachate at sites where organic concentrate can be disposed on-site by spray irrigation or recirculation, or where the volume of leachate must be reduced for off-site disposal. A membrane-based process may be particularly suitable for application at sites where spray irrigation practices are limited by excessive hydraulic loading or toxic metals, or where immediate start-up of a treatment process is required. Reverse osmosis has been shown to be effective as a polishing step for leachate treatment. It would be suitable for removal of residual TDS in partially treated leachates, as well as concentrating residual organics, and would assure production of a high quality effluent.

This testing program was conducted on a relatively dilute landfill leachate in terms of organic content. Application of the membrane-based process to higher strength leachates may result in lower volume reductions achievable or poorer effluent qualities for equivalent recoveries, and therefore additional testing would be necessary to evaluate the technical performance and cost-effectiveness of a membrane based process for the treatment of higher strength landfill leachates.

2.0 INTRODUCTION

2.1 Background

Landfill leachates are complex wastes containing a wide spectrum of organic contaminants, typically including decomposition products from organic material, petroleum hydrocarbons and solvents, as well as a variety of inorganic contaminants which may pose a threat to surface or groundwater use. In recognition of this potential long-term threat, the Ontario Ministry of the Environment is in the process of evaluating appropriate treatment measures.

The quality of landfill leachate varies substantially between sites depending on such factors as the type of waste disposed, site specific hydrogeology, age of the landfill, and the relative biodegradability of the different organic contaminants present. As a result, a variety of treatment processes have been considered and evaluated for the treatment of landfill leachates from various sites in various stages of decomposition.

Biological treatment has been used reliabily and effectively, and many researchers have demonstrated different biological processes for leachate treatment. Biological processes which have been investigated and evaluated include aerated lagoons, activated sludge, sequencing batch reactors, rotating biological contactors (RBC), anaerobic lagoons, and recirculation systems (Chian et. al., 1976; Boyle, et. al., 1984; Forgie, 1988; Fein and Yu, 1988). Studies have shown that certain leachates from older landfills have a higher concentration of larger molecular weight refractory organic contaminants and are not readily amenable to biological treatment. Other problems associated with activated sludge processes may include hydraulic and organic overloading, lack of nutrient addition, and inadequate aeration (Robinson and Maris, 1983). Heavy metal concentrations may also upset biological treatment processes (Boyle and Ham, 1984). Anaerobic systems generally require a large amount of land area and may have associated odour problems.

The complex nature of landfill leachates necessitates a complete treatment process able to treat organic as well as inorganic contaminants, thus multistage treatment processes are often necessary. For some applications, physical/chemical treatment alone or in combination with biological treatment has demonstrated the potential for contaminant removal. A recent review of physical/chemical treatment processes for landfill leachate treatment was undertaken by Forgie (1990b). This includes an assessment of precipitation and coagulation, chemical oxidation, activated carbon, air stripping, and membrane separation.

Membrane based systems hold significant potential for treatment of such leachates and may be incorporated with other pre and post treatment processes, including biological or physical/ chemical treatment as appropriate. Cross-flow membrane filtration processes, including microfiltration (MF), ultrafiltration (UF), and reverse osmosis (RO), have been applied to a wide variety of industrial waste water streams, including electroplating, petroleum, petrochemical, pulp and paper, and food and beverage plants. Numerous reviews of process principles and applications are available in the literature (Applegate, 1984; Leeper et. al., 1984). Recent developments in membrane chemistry and system design have served to improve process reliability and thereby improve process economics.

Membrane filtration processes, like reverse osmosis, are often operated in a cross-flow mode with flow of feed across the membrane surface and have three continuous flow streams (feed, permeate and concentrate). Traditional filtration is referred to as dead-end filtration because feed flow is directly through the filter and all the material that is to be removed accumulates on the filter surface, therefore increasing the resistance to filtration. Cross-flow filtration minimizes the accumulation of material on the filter surface by continuously pumping a turbulent feed across the membrane surface.

The three main membrane filtration processes (MF, UF and RO) are all based upon a pressure driven flow through a semi-permeable membrane, however they each have different membrane and separation characteristics, and optimal operating conditions.

Microfiltration processes have typical filtration pore diameters of 0.08 to 1.0 µm and effectively remove suspended solids which are not easily settled. MF has been applied to the treatment of many contaminated wastewaters as the solids removal step after chemical precipitation of toxic metals. The MF process provides assured discharge water quality, is less susceptible to upset conditions than conventional solids removal processes, and is not affected by poor settling characteristics of the solids produced.

Ultrafiltration processes operate in a smaller filtration range, with typical pore diameters from 0.002 to 0.1 µm, and are commonly used for the concentration of wastewater containing emulsified oils or large molecular weight organic contaminants.

Reverse osmosis processes operate in an even smaller filtration range, with pore diameters generally less than 0.002 µm, and are used for the removal of dissolved solids (salts) and dissolved organic contaminants. Considerable work has been done evaluating the use of RO for the removal of problematic compounds from a variety of waste streams.

Research undertaken over the last few years has demonstrated the technical feasibility of reverse osmosis and other membrane processes in various capacities for the treatment of industrial wastes. Research for application on landfill leachate has been carried out in the U.S. (Slater et. al., 1985, Syzdek & Ahlert, 1984) and in Canada (Whittaker et. al., 1985, Donison et. al., 1988, Krug and McDougall, 1988). This research is summarized and reviewed by Krug and McDougall (1988). Recent studies include physical/ chemical treatment of dilute organic wastestreams by ozonation and reverse osmosis (Williams et. al., 1990). The researchers examined performance of thin-film composite membranes for rejection of chlorophenols and chloroethanes under various laboratory test conditions. Pretreatment by ozonation followed by membrane separation was successful in reducing chlorophenol concentrations of 50-150 mg/L in the feed stream by over 80%. Reverse osmosis and ultraviolet photolysis/ozonation (UV/O_3) in various process combinations were investigated for treatment of leachate containing parts per million levels of metals and solvents (Whittaker and Keller, 1990). The field testing program demonstrated that UV/O_3 effectively destroyed all organic componds in the leachate under optimum test conditions. Reverse osmosis followed by UV/O_3 treatment of the permeate resulted in an effluent which was suitable for re-injection or discharge to a municipal treatment facility. The study also recommended that hydroxide precipitation of metals followed by cross-flow microfiltration should be the first step in any treatment process for this application.

Both physical/chemical and biological treatment processes were recently evaluated for treatment of hazardous landfill leachate and contaminated groundwaters by Ahlert and Kosson (1990). The studies were undertaken using high strength, complex landfill leachates (DOC 8,000 - 12,000 mg/L, TDS 15,000 - 20,000 mg/L) containing both organic and inorganic contaminants. Physical/chemical treatment was generally found necessary prior to both biological and membrane based treatment, with the best results obtained using lime precipitation. Reverse osmosis was shown effective for lime-pretreated, moderate strength leachates, and proved successful for removal of inorganic contaminants after biological treatment. Ultrafiltration was not effective as a single stage treatment process since it did not remove lower molecular weight organics typically found in industrial landfill leachates, however the possible application as pretreatment for RO was identified. Lime pretreatment was shown to be more effective on older leachates containing higher molecular weight organics for removal of COD and TOC.

Previous studies carried out by ZENON on behalf of Environment Canada (Donison et. al., 1988) illustrated the feasibility of RO in the field. The results indicated excellent removals of volatile organics in dilute landfill leachate and petrochemical drainage waters. The RO concentrate was further treated by carbon adsorption. The study also demonstrated through preliminary trials that ultrafiltration pretreatment prior to reverse osmosis was effective in reducing downstream fouling and extending membrane life when processing highly fouling raw feeds.

Bench scale study was previously undertaken (Krug and McDougall, 1988) to evaluate the potential for reverse osmosis as part of a complete process developed for the treatment of landfill leachates in Ontario. The complex nature of landfill leachates necessitates a treatment process capable of treating both inorganic and organic contaminants, thus an integrated schematic was developed and evaluated based on laboratory testing with actual leachate samples.

Results of the bench scale study confirmed the technical feasibility of a membrane-based process. An optimized two-stage process design was developed, incorporating precipitation/

microfiltration and reverse osmosis, to produce an effluent suitable for discharge and concentrated waste streams to be further treated, recycled, or disposed.

A schematic of this process is shown in Figure 2-1. The first stage in the process involves pH adjustment and precipitation of heavy metals and hardness followed by microfiltration. Concentrated precipitated material from the microfilter is dewatered in a plate and frame filter press and either solidified for final disposal on-site or hauled off site to a secure landfill. The permeate from the microfiltration system is fed to a reverse osmosis unit for removal of dissolved metals and organics.

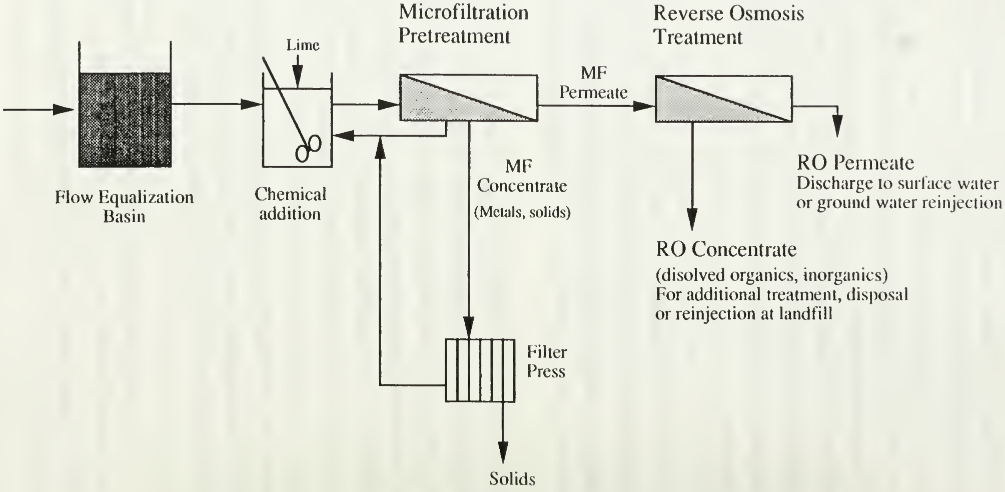
Bench scale test results demonstrated that precipitation/microfiltration treatment of landfill leachate is effective in removing virtually all iron and suspended solids, and in reducing heavy metals by an average of 99%. The permeate was further polished by reverse osmosis which was successful in removing 98% of both the TOC and conductivity from the pretreated feed.

The potential benefits of the precipitation/microfiltration process over conventional precipitation and settling processes include the ability of the process to completely remove toxic heavy metals and remain insensitive to upset conditions and sludge settling characteristics. The MF process is also compact in size relative to conventional clarifiers. The treated effluent from an optimized system also offers the potential to generate a permeate suitable for discharge to conventional sewage treatment, or may be compatible with other leachate management strategies such as land irrigation since the toxic metals, suspended solids and many chlorinated organics were shown to be effectively removed. The resulting sludge (MF concentrate) would be dewatered and the filter cake disposed in a secure landfill, while the MF permeate containing dissolved organics and inorganics could be used for spray irrigation, discharged to sewer or further treated.

Depending upon the leachate characteristics and treatment objectives, the permeate or filtered water from the first stage of the process could then be subjected to final polishing by reverse osmosis. The RO process concentrates the remaining inorganic and organic contaminants

Figure 2-1

Potential Process Schematic for Treatment of Landfill Leachate


Microfiltration Pretreatment
Reverse Osmosis Treatment
Lime
MF Permeate
Flow Equalization Basin
Chemical addition
MF Concentrate
(Metals, solids)
RO Permeate
Discharge to surface water or ground water reinjection
RO Concentrate
(disolved organics, inorganics)
For additional treatment, disposal or reinjection at landfill
Filter Press
Solids

in the leachate and produces a clean permeate of a very high quality suitable for discharge in many locations. The concentrate from the RO process, containing components which were not removed in the first stage precipitation/microfiltration process, can be disposed of off-site, recycled to the landfill site itself or treated in a concentrated form. The potential benefits of using reverse osmosis to polish the MF permeate include reduced hydraulic loading on any downstream treatment processes, reduction of volume for off-site disposal, and generation of a low dissolved solids clean water product stream. Many researchers have noted the viability of recycling landfill leachate back to the site to enhance the biodegradation of organics present and prevent migration of leachate off-site. However, two problems which have been identified with this process are inhibition of biological activity by heavy metals and some organics in the raw leachates, as well as the build up of water within the site itself when recirculation is combined with natural sources, such as rainfall. Similarly, at sites where spray irrigation of leachate is practiced, problems have been identified with toxicity of heavy metals to vegetation and excess volume requiring disposal. The concentrate from the RO would be primarily organic in nature, thereby reducing metal toxicity effects. The reduction in hydraulic loading achievable through this process may be of significant benefit when recirculation, spray irrigation, hauling or incineration are used for disposal.

This report presents the results of a two month field demonstration of the developed process, and presents a technical and economic process evaluation. The report includes a discussion of treatment objectives, a review of the principles of each component of the process, a description of the system design and field testing program, together with a discussion of results and an assessment of potential application in leachate remediation strategies.

2.2 Objectives

In summary, the objectives of this study were:

- to conduct a field demonstration of a membrane based process for treatment of landfill leachate,
- to design a pilot scale treatment system and operate the process at a landfill site for a period of two months, and

- to provide an assessment of the technical feasibility and cost of the process based on longer term operational data, and make recommendations for future field applications at this and other problem landfill sites in Ontario.

3.0 PROCESS DEVELOPMENT

3.1 Leachate Characteristics and Treatment Objectives

A candidate test site suitable for pilot scale evaluation was selected for this study based on leachate quality, quantity generated, and treatment requirements, as well as site access and availability of support services.

Research by University of Guelph at the Muskoka Lakes landfill site evaluated spray irrigation as a leachate management strategy (McBride et. al., 1988). The researchers concluded that a pretreatment system is necessary to prevent damage to vegetation and groundwater supplies, and they identified reverse osmosis as one potential process which appears ideally suited. The report indicated that the leachate quality falls within the range of characteristics typically encountered, and confirms the potential suitability of the site for physical/chemical treatment in terms of BOD:COD ratio, as well other organic and inorganic contaminants present .

The volume of leachate requiring treatment at the Muskoka Lakes landfill site is expected to exceed the capacity of the current spray irrigation system, thus a process capable of reducing both chemical concentration and hydraulic loading is required at the site. Based on this information, the site was selected for the demonstration of the membrane based process, since results of the field trial could be used to evaluate both the relative merits for incorporation into a spray irrigation leachate management program, as well as generate data regarding overall process effectiveness for generating an effluent suitable for sewer or surface discharge.

A sample of leachate from Muskoka Lakes landfill site was collected for chemical analysis and confirmatory bench scale treatability testing. Table 3-1 presents the chemical composition of the leachate sample. As shown in the table, the primary contaminants of concern for surface discharge are TOC, BOD, COD, iron, manganese, and solids. Key volatile organic contaminants are shown to be toluene, with low levels of benzene and ethylbenzene. These compounds are found in aromatic solvent mixtures, but may also be derived from other sources. Low levels of several chlorinated solvents were also detected, including 1, 1-Dichloroethane and 1,2-

Table 3-1
Raw Leachate Initial Characterization

Parameter (mg/L)	
pH (@ 20°C)	5.85
Conductivity (μmho)	655
Turbidity (ntu)	320
TDS	570
TSS	203/206
COD	510
BOD	280
TOC	180
DOC	210
Ammonia (as N)	16
TKN (as N)	15
Hardness (as CaCO3)	223
Fluoride	8.6
Chloride	13
Nitrite (as N)	<0.2
Bromide	<0.8
Nitrate (as N)	<0.2
Phosphate (as P)	<0.8
Sulphate	1.3
Alkalinity (as CaCO3)	200
Calcium	73
Magnesium	9.9
Sodium	15
Potassium	24
Aluminum	<0.03
Barium	0.21
Beryllium	<0.001
Boron	0.2
Cadmium	<0.002
Chromium	<0.004
Cobalt	0.011
Copper	<0.006
Iron	30 *
Lead	<0.02
Maganesium	2.3
Molybdenum	<0.02
Nickel	<0.01
Phosphorous	0.072
Silicon	6.2
Silver	<0.01
Strontium	0.46
Sulphur	1.8
Thallium	<0.06
Titanium	<0.01
Vanadium	<0.005
Zinc	<0.005
Zirconium	<0.01

EPA-624 Priority Pollutants

Parameter (μg/L)	MDL	Method Blank	Sample
Chloromethane	2.3	<	<
Vinyl chloride	2.9	<	<
Bromomethane	2.4	<	<
Chloroethane	2.3	<	<
Trichlorofluoromethane	0.3	<	<
1,1-Dichloroethene	0.4	<	<
Methylene chloride	0.3	6.0	<
trans-1,2-Dichloroethene	0.4	<	2.8
1,1-Dichloroethane	0.5	<	3.7
Chloroform	0.4	<	<
1,1,1-Trichloroethane	0.6	<	<
1,2-Dichloroethane	0.4	<	<
Carbon tetrachloride	0.3	<	<
Benzene	0.2	0.45	6.0
1,2-Dichloropropane	0.5	<	<
Trichloroethene	0.3	<	2.1
Bromodichloromethane	0.4	<	<
2-Chloroethlyvinyl ether	2.9	<	<
cis-1,3-Dichlorpropene	0.7	<	<
Toluene	0.4	<	180
trans-1,3-Dichloropropene	1.1	<	<
1,1,2-Trichloroethane	0.6	<	<
Dibromochloromethane	0.4	<	<
Tetrachloroethene	0.2	<	<
Chlorobenzene	0.6	<	<
Ethylbenzene	0.3	<	16
Bromoform	0.3	<	<
1,1,2,2-Tetrachloroethane	0.3	<	<
Surrogate Recovery (%)			
1,2-Dichloroethene-d4		101	104
Toluene-d8		103	107
Bromofluorobenzene		102	102

MDL - minimum detection limit
< - less than MDL
data blank corrected

* Iron in all other raw leachate samples used later in the study ranged from 100-200 mg/L

Dichloroethane. These results are comparable, although iron and toluene are somewhat lower, to the data reported by other researchers for this particular leachate (McBride et. al., 1988).

After appropriate treatment, the treated leachate or RO permeate at this and other landfill sites in Ontario would be discharged to surface water, discharged to sewer, reinjected to the aquifer, or used for spray irrigation. In an attempt to meet the most stringent guidelines, both surface water quality objectives (Ontario Ministry of the Environment, 1984) and drinking water quality objectives (Ontario Ministry of the Environment, 1983; Health and Welfare Canada, 1989), were used as criteria for assessing the technical effectiveness of the process. Actual effluent requirements are established on a case-by-case basis, depending on receiving water quality, "industry" specific limits, and specific Certificates of Approval. The pilot unit was therefore designed and operated with the objectives of maximizing the quality of the final treated effluent within the constraints of the existing process design.

3.2 Microfiltration

Cross-flow microfiltration is a separation process which removes very fine suspended solids and colloids from a variety of waste and process streams. Typical pore sizes for MF, UF and RO processes are shown in Figure 3-1. Figure 3-2 schematically illustrates cross-flow filtration. The species present in the stream are either rejected or accepted through the semi-permeable membrane on the basis of size. The filtration surface is a strong polymeric membrane cast on the inside surface of a support tube. Feed is pumped at relatively low pressures (up to 414 KPa or 60 psi) through the membrane tube. The water and dissolved components pass through the membrane as clean filtrate or permeate, while suspended solids and fine particulate material are retained by the membrane and remain with the feed. The feed becomes more concentrated as it flows down the membrane tube. Turbulence from the flow through the tube helps keep the filtration surface clear of build up of some contaminants which tend to reduce the filtration or permeate rate. This self cleaning feature allows high levels of solids (2-4%) to be processed with out blocking the filtration surface. Periodic backwashing and membrane cleaning solutions are also used to maintain flux rates. The frequency of cleaning is dependent upon the nature of the feed and processing objectives. The concentrated feed stream leaving the tube is

Figure 3-1

Size Range for Cross Flow Filtration

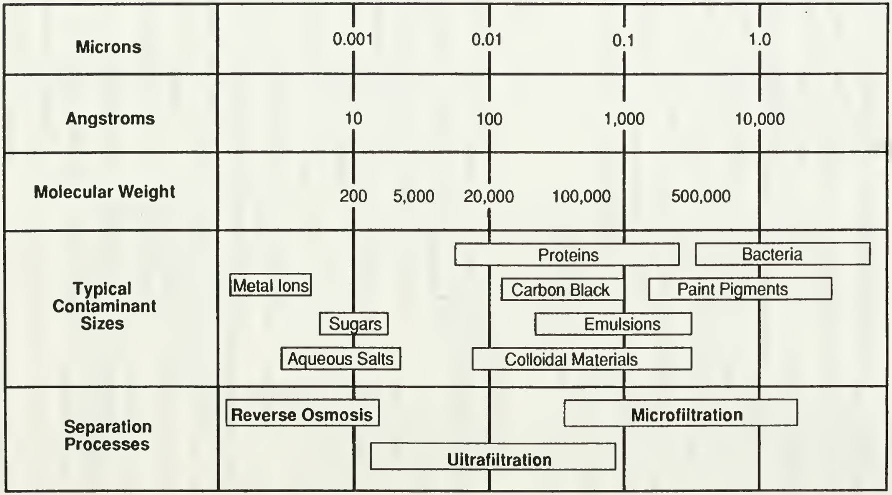
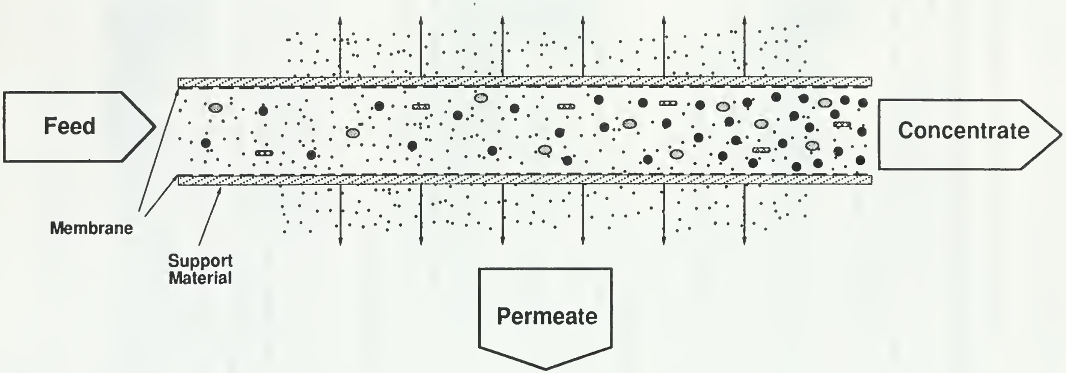


Figure 3-2

Cross Flow Filtration



referred to simply as concentrate.

The performance of all microfiltration systems is affected by variations in operating temperature, and membrane throughput or flux will increase with increasing temperature up to the maximum operating limitations of the membrane. The membrane flux will be affected by specific chemistry of the membrane and interactions with feed and any feed additives, the operating pressures, and the extent of feed concentration.

The results of previous bench scale testing (Krug and McDougall, 1988) and confirmatory tests on this leachate as described in Chapter 5.1 indicated that pretreatment by lime to precipitate metals and soda ash to precipitate the excess calcium salts present after lime addition is required to maximize performance of the downstream RO for this application.

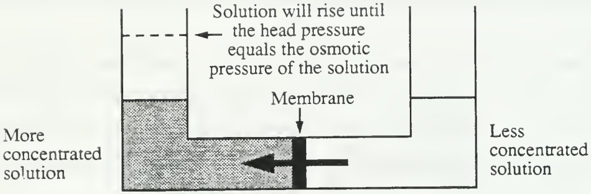
3.3 Reverse Osmosis

In reverse osmosis the contaminated water is passed under pressures up to 6,900 KPa or 1,000 psi across a membrane surface. At the membrane surface, pure water passes through the membrane, leaving the suspended and dissolved contaminants concentrated on the feed side.

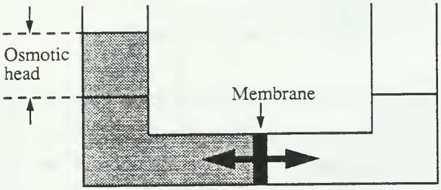
The amount of material removed (rejected) by the membrane is dependent on the type of reverse osmosis membrane used and the types of dissolved materials present. Rejection levels are dependent on the size and charge of the dissolved molecule, with larger molecules and those with higher charges being more readily rejected.

The concept of reverse osmosis is illustrated in Figure 3-3. As shown in Part A of Figure 3-3, if a more concentrated salt (or other dissolved material) in water solution is placed opposite a semipermeable membrane from a less concentrated solution, the natural process of osmosis will occur. The membrane will permeate water from the less concentrated solution into the more concentrated solution until an equilibrium is established. The difference in pressure that is created across the membrane at equilibrium, as shown in Part B of Figure 3-3, is known as the osmotic pressure of the solution.

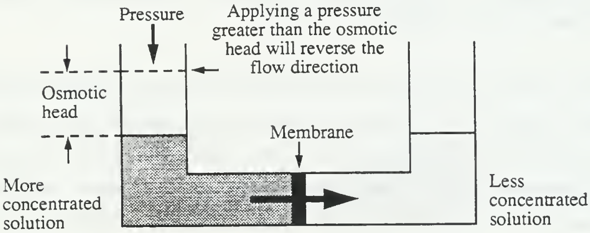
Figure 3-3
Concept of Reverse Osmosis


Solution will rise until the head pressure equals the osmotic pressure of the solution
Membrane
More concentrated solution
Less concentrated solution

A) Osmosis



B) Equilibrium


Pressure
Applying a pressure greater than the osmotic head will reverse the flow direction
Osmotic head
Membrane
More concentrated solution
Less concentrated solution

C) Reverse Osmosis

If it is desirable to remove water from the more concentrated solution, pressure must be applied to the more concentrated solution as illustrated in Part C of Figure 3.3. In order to have permeation of water from the more concentrated solution to the less concentrated solution (in effect reversing osmotic flow) the amount of pressure applied must be greater than the osmotic pressure.

The amount of pressure required to produce a reverse osmosis effect is dependent on the concentration of salts in the original solution and the amount of water that must ultimately be removed. The more concentrated the starting solution and the higher the concentration factor desired, the higher the pressure that must be applied so that reverse osmosis will occur. Typical operating pressures range between 1,380 - 6,900 KPa (200 - 1,000 psi).

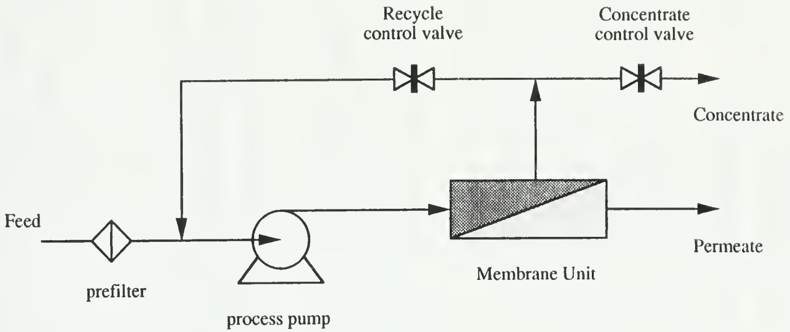
The basic components of a reverse osmosis system are illustrated in Figure 3-4. As can be seen, the system is very simple, consisting of a prefilter, a process pump, a reverse osmosis membrane module, and flow/pressure control valves. As a result of their simplicity of design, reverse osmosis systems are inherently easy to operate and maintain.

The concentration factor (ratio of the feed volume to concentrate volume) can be controlled by controlling the extent of concentration within the RO system. The concentration factor may be limited by the osmotic pressure or, as is more frequently the case in natural water systems, by the precipitation of inorganic salts at the membrane surface. Inorganic salts precipitate when anions and cations have been concentrated past their solubility limit. The result is the formation of scalants that greatly reduce membrane flux. This problem can often be minimized by reducing the pH of the feed to increase the solubility of some of the more commonly precipitating metals or by adding antiscaling chemicals to the feed.

Reverse osmosis membranes can be configured in several ways. The basic configurations commercially available are spiral, tubular, hollow fibre, and plate and frame. Each of the configurations has a different packing density with tubular systems having the least dense packing and spiral systems having the most dense packing. Most RO systems operate with membranes in a spiral configuration to maximize the packing density and minimize membrane costs. The spiral

Figure 3-4

Basic Membrane System Flow Schematic



modules have thin channels on the feed side of the membrane which are susceptible to plugging by suspended solids in the feed. Pretreatment for the removal of suspended solids is required to ensure reliable operation of spiral RO membranes.

4.0 FIELD TESTING PROGRAM

4.1 Site Description

The Muskoka Lakes sanitary landfill site, accessible from Muskoka Rd. 26, is located on Concession 1 of the Medora Ward in the Township of Muskoka, District Municipality of Muskoka. The site is situated approximately 400 metres from Lake Muskoka. A comprehensive description of the site and a review of site hydrogeology is presented in a report by McBride et. al. (1988) which reviews and discusses the treatment of landfill leachate by spray irrigation.

The area was used as a landfill site from 1976 to 1980. Estimates indicate that leachate will be generated at the site at a rate of at least 2.4×10^7 L /year (McBride et. al., 1988) . Since 1980, spray irrigation has been practiced at the site and despite expansion of the system over the years, the maximum loading, based on application rates and available land area, is 2.0×10^7 L between April and October. Since the volume of leachate generated would exceed capacity of the current process, alternative mitigation procedures are currently being evaluated.

The leachate is presently collected in a trench which is situated downslope of the site. It is collected in a sump and pumped to two settling lagoons, where a limited degree of natural aeration and biodegradation occurs, and then pumped to a network of 72 spray nozzles for land distribution over a forested area approximately 4.3 hectares in size. The site is illustrated in Figure 4-1.

For the field testing program, the pilot treatment unit was situated inside the pumphouse adjacent to the existing lagoons. Since some degree of treatment and settling occurs in the lagoon, the leachate was drawn directly from the sump at the base of the landfill to obtain a higher strength leachate.

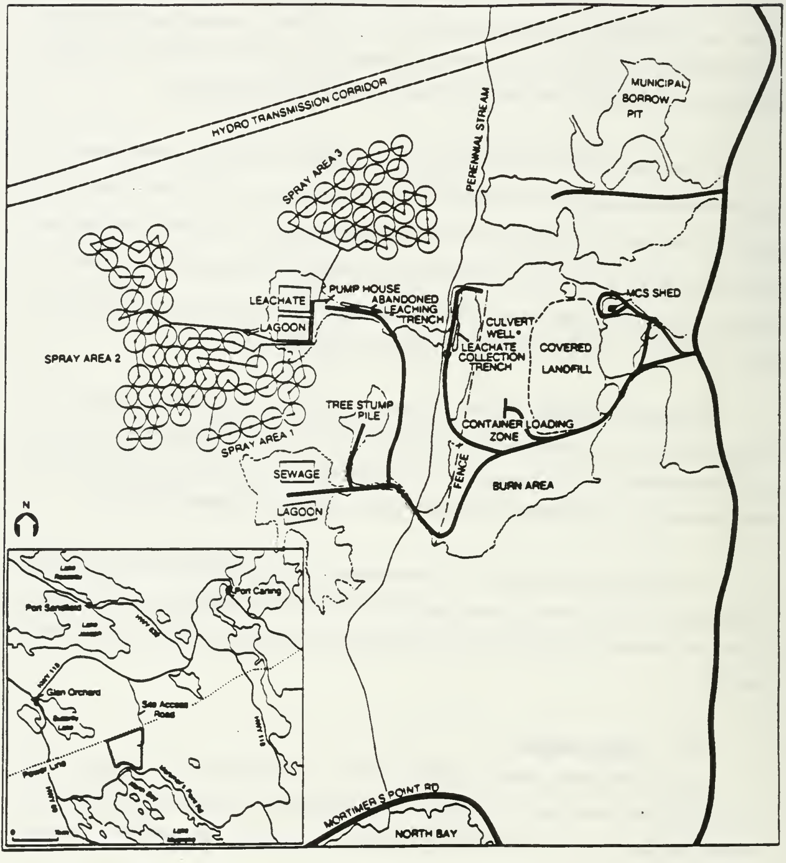
4.2 System Design

For the field testing study, ZENON's pilot scale microfiltration and reverse osmosis treatment systems were used. The systems were retrofitted and connected together with all ancillary equipment to provide a fully portable skid mounted system consisting of feed tanks,

Figure 4-1

The Muskoka Lakes MSW Landfill Site (Scale 1:6, 300)

(From McBride et al, 1988)



pumps, and associated piping. The components and operation of each system are described in the following sections.

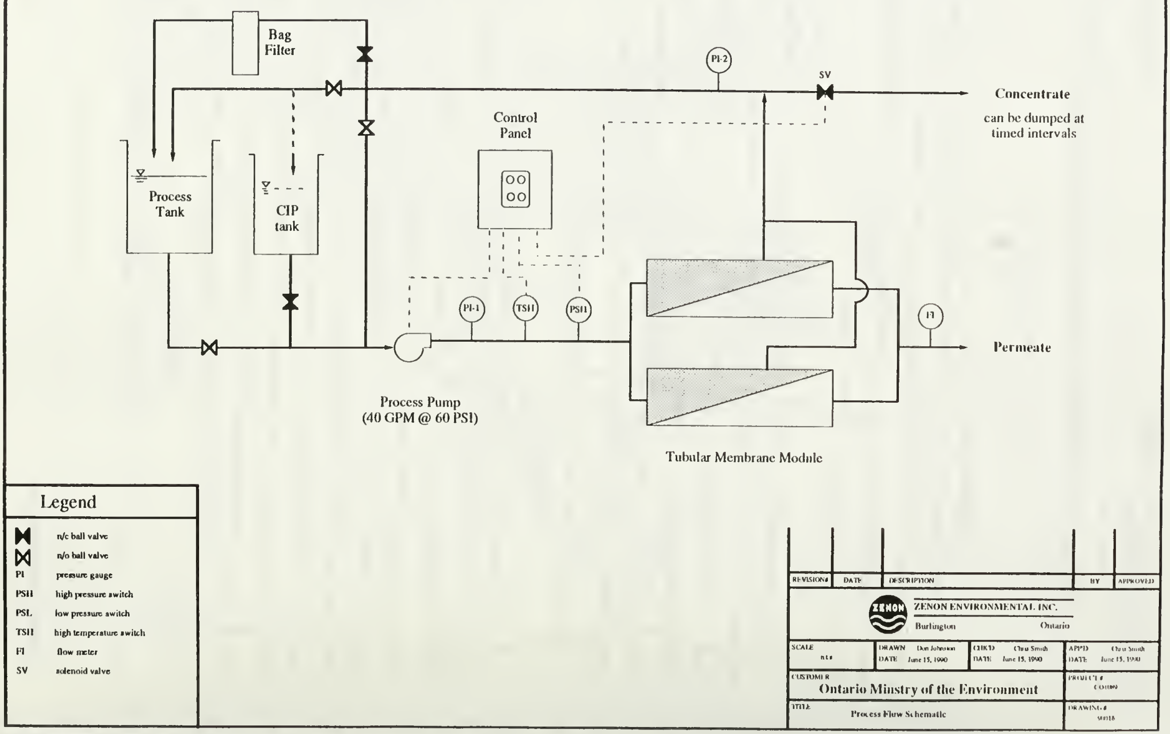
4.2.1 Equipment Description

The microfiltration test unit consisted of an 1800 L polyethylene tank, a single stage centrifugal pump, two ZENON Z-8 tubular membrane test modules connected in parallel , a central control panel, a clean-in-place tank, and associated tubing, valves, and pressure gauges. A schematic of the MF test system is shown in Figure 4-2.

The microfiltration membranes used for the field testing program are a polysulphone-based membrane, referred to as the ZENON AST membrane, with a neutral charge and a molecular weight cut off of approximately 200,000, or pore size of 0.03 µm. These membranes were designed for applications with inorganic suspensions containing some dissolved organics. ZENON's patented Z-8 Module uses tubular microfiltration membrane modules with an internal series flow configuration. Each tube is 2.1 cm (0.84") in diameter and approximately 1.96 mm (77") in length, for a total surface area per module of 0.98 m^2 (10.5 ft^2).

The process tank was equipped with a mixer to aid in the pretreatment of the raw leachate. No cooling system was used with the MF system since the raw leachate was only 6-9 °C and the ambient temperature ranged from 12°C to less than zero. These cool temperatures eliminated the need for additional cooling water. The process temperature was monitored with an in line temperature probe. The full capacity of the process pump (150 Lpm or 40 USgpm at 60 psi) was used to provide the flow through the membranes. Inlet and outlet pressure gauges were used to monitor the membrane pressure. A ball valve on the outlet from the membranes was used to control the back pressure on the membranes. The permeate flow rate was monitored with an in-line flowmeter. High temperature (40°C) and low pressure (40 psig) shut off switches were used to protect the membranes and process pump. All system piping was constructed of PVC or 1 1/2" braided hose.

Figure 4-2
Microfiltration Test System



The reverse osmosis test system consisted of a 650 L polyethylene tank, a feed pump, a process pump, one Filmtec FT-30 4" x 40" spiral membrane module with a surface area of 7.90 m^2 or 85 ft^2 a central control panel, a clean-in-place tank, interconnecting piping, valves, and pressure gauges. A schematic of the RO test system is shown in Figure 4-3. The RO membrane was selected based on results of previous tests (Krug and McDougall, 1988), and performance in other related applications.

The cooling water supply used for the RO system was pumped from one of the lagoons. The operating temperature was monitored with an in-line temperature probe. The feed was transferred with a single stage centrifugal pump, with a capacity of 4 L/min (10 US gpm) at 30 psig. The process pump was a multi-stage centrifugal pump with a capacity of 19 LPM (5 US gpm) at 400psig. Flow meters were used to monitor both concentrate and permeate flows. The membrane back pressure was monitored with inlet and outlet pressure gauges, and was controlled with a needle valve. High and low pressure and high temperature switches were used to protect the membrane and process pump. The high pressure side of the system was constructed of 316 stainless steel. Low pressure piping was of PVC.

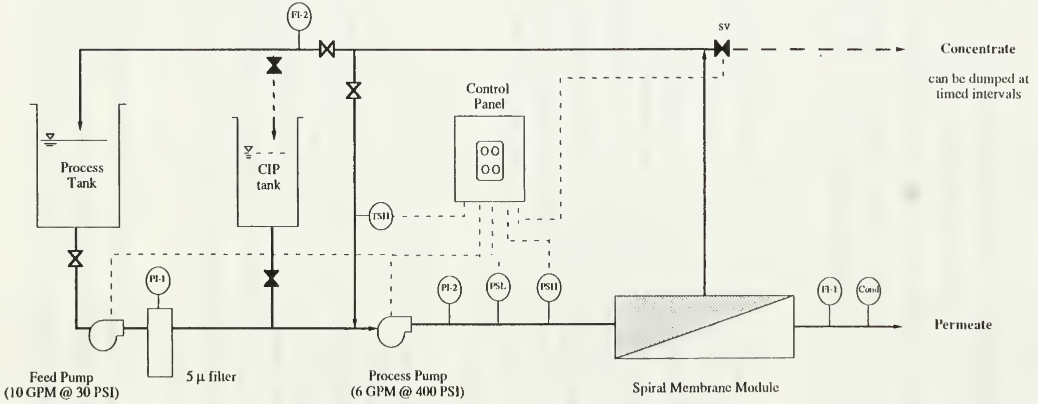
4.3 System Operation and Monitoring

4.3.1 System Operation

The MF/RO system was commissioned at the Muskoka Lakes Landfill Site in September, 1989. Experimentation took place from October 3 to November 15, 1989. The system was initially operated in batch concentration and stability modes. Later a modified batch operation was used and longer duration stability tests were conducted. The system was started each morning and operated for a 7 - 9 hour interval and then shut down over night. The system was cleaned at the end of each test (roughly every five days).

The system was set up in the pump house at the base of the holding lagoons. A water flux test was carried out with the MF system, and a salt flux test (using 2000 ppm NaCl) was conducted with the RO to obtain base line flux rates and to ensure proper working order.

Figure 4-3
Reverse Osmosis Test System



Legend

⧓	n/c ball valve
⋈	n/o ball valve
PI	pressure gauge
PSH	high pressure switch
PSL	low pressure switch
TSH	high temperature switch
FI	flow meter
COND	conductivity probe
SV	solenoid valve

REVISION#	DATE	DESCRIPTION	BY	APPROVED

ZENON ENVIRONMENTAL INC.
Burlington Ontario

SCALE n.t.s	DRAWN Don Johnson DATE June 15, 1990	CHKD Chris Smith DATE June 15, 1990	APPD Chris Smith DATE June 15, 1990
CUSTOMER Ontario Ministry of the Environment			PROJECT # C0069
TITLE Process Flow Schematic			DRAWING # 90017

The raw leachate was pumped from the sump at the foot of the landfill through 215 meters of plastic tubing to the MF process tank. The process tank was left outside for the duration of the test period. During the initial tests, the raw leachate was treated with lime (calcium hydroxide) at a dosage of 800 mg/L to raise the pH to 10. Soda ash (industrial grade sodium carbonate) was also added at a dosage of 1.1 mg/L to provide excess carbonate to precipitate the calcium. For the final three tests the pH was raised to only 8 and no soda ash was used.

The MF system was started with all process flows returning to the tank (stability mode) and the back pressure valve fully open. Once the pretreatment was completed, the mixer was turned off since the system return line provided sufficient turbulence in the process tank. The back pressure valve was closed slowly until a 60 psig inlet pressure was obtained.

The RO feed tank was filled with MF permeate as it was produced. The RO system was also turned on with all process flow returning to the RO feed tank and the back pressure valve fully open. After all of the trapped air was removed from the system, the back pressure was increased to 400 psig.

At the end of each test both the MF and RO membranes were cleaned with an acidic cleaner (ZENON MC-1). The RO cartridge prefilter was changed at the time of membrane cleaning. The raw leachate transfer tubing was inspected daily for leaks.

During tests eleven and twelve the pH of the RO feed was lowered to between 6 and 7 by addition of 50% HCl.

4.3.2 Monitoring

The MF unit was monitored for inlet and outlet pressures, permeate flow rate, and concentrate temperature every fifteen minutes for the first hour of operation, and every thirty minutes thereafter. The RO unit was monitored for prefilter pressure, membrane inlet pressure, concentrate and permeate flow rates, concentrate temperature, and permeate conductivity every fifteen minutes for the first hour, and every thirty minutes thereafter.

4.3.3 Analysis

Chemical analysis was conducted throughout the field test program to assess the system performance. Routine analysis included pH, total suspended solids (TSS), total dissolved solids (TDS), conductivity, alkalinity, anions and cations, and total organic carbon (TOC). Further characterization included biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic halogen (TOX), volatile organics by gas chromatography / mass spectrometry (GC/MS) (EPA Method 624) and extractable organics (EPA Method 625). The methodologies used for all analysis are given in Appendix A.

5.0 RESULTS AND DISCUSSION

5.1 Pretreatment Selection

Reverse osmosis membranes require pretreatment to remove particles larger than 5 μm and to remove any feed components such as free or floating oil or calcium which could potentially foul, damage or scale the downstream membrane units. The impact of complex wastes on membrane performance is difficult to predict and the design of the process and compatibility of feed and membrane components must usually be determined based on laboratory and/or field testing.

Previous bench-scale laboratory testing using a membrane based system for treatment of leachate from another landfill site evaluated several pretreatment options (Krug and McDougall, 1988). Several methods were evaluated for precipitation of dissolved metals, and other inorganics which would adversely affect the membrane performance. These methods included: addition of caustic (NaOH) to pH 8, addition of lime to pH 10, addition of lime to pH 10 combined with soda ash, and addition of lime to pH 10 with powdered activated carbon. The latter was included to evaluate the potential for organic removal. The precipitated contaminants and other suspended solids were removed in a cross-flow microfiltration process. The study concluded that of these options the most appropriate pretreatment method in terms of MF flux, and effluent quality was the addition of lime to pH 10 combined with soda ash. In this scenario, referred to as lime-soda ash softening, the high pH will precipitate metals as metal hydroxides and the soda ash will provide carbonate to precipitate the excess calcium as calcium carbonate.

Based on these earlier results several pretreatment options were evaluated at bench scale using Muskoka Lakes Landfill leachate to confirm dosages and to finalize process design. Both caustic soda (sodium hydroxide) and lime were used to precipitate metals. In most waste treatment applications, lime is less expensive than caustic and although more sludge is generated, the solids separation and sludge dewatering are much easier. As pretreatment to RO, it may be desirable to precipitate excess calcium with soda ash to prevent scaling on the RO membrane surface. Caustic soda is easier to handle and results in lower sludge production, however, the sludge is usually more gelatinous and therefore more difficult to dewater.

A series of six bench scale tests were conducted to evaluate pretreatment options for the leachate under consideration. As shown in Figure 5-1, the pH was adjusted to 8, which is the minimum solubility for iron hydroxide, and 10, which would minimize solubility of other toxic heavy metals such as nickel, zinc, and cadmium. The effects of filtration alone, as well as aeration to oxidize ferrous iron to ferric which would readily precipitate as ferric hydroxide, were also measured. A 0.45 μm membrane filter was used to simulate the filtration process and compare the relative performance of each option prior to testing with a small scale microfiltration module. Since iron is the main inorganic contaminant of concern in the leachate under study, it was used as the indicator of performance during the screening studies.

The combinations of the treatment options considered are presented in Table 5-1. Filtration of the untreated sample demonstrated that of the 43 mg/L of iron which passed through the filter, approximately 36 mg/L is in the oxidized ferric form. It was expected that little or no ferric iron would pass into the filtrate since the theoretical solubility of ferric hydroxide at pH 6 is only about 0.5 μg/L as Fe in pure solution. The fact that most of the iron was present in the ferric form indicates that the iron hydroxide was likely dispersed in a very fine precipitate which passed through the 0.45μm filter.

As expected, raising the pH of the leachate with either caustic or lime reduced the residual levels of iron in the filtrate. When lime was used, soda ash was added in stoichiometric amounts to precipitate excess calcium as calcium carbonate in order to minimize downstream fouling of the RO membrane. Filtration tests illustrated that slightly lower residual iron levels were attainable with caustic compared to lime/soda ash treatment. Both treatments resulted in low levels of iron which would not adversely affect membrane performance. Tests were then conducted using a small configured MF test module (tests 5 and 6), and demonstrated that both chemical treatment methods were able to reduce iron levels to less that 1 mg/L, with the lime/ soda ash treatment showing slightly lower residual iron levels. Test data is given in Appendix B (Tables B-1 and and B-2). Tests with the tighter microfiltration membrane demonstrated that most of the iron could be removed, however residual iron levels were higher than expected based on theoretical solubility.

Figure 5-1
Schematic of Bench Scale Testing Program

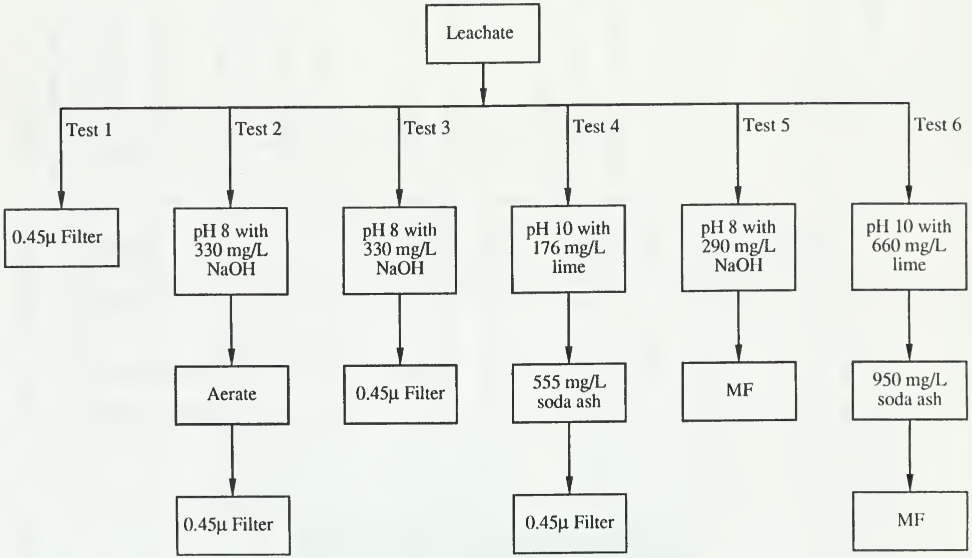


Table 5-1
Residual Levels of Iron in the Treated Leachate Following the Bench Scale Tests (refer to fig. 5.1)

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Total Iron (mg/L)	43.1	1.7	0.75	3.07	0.85	0.58
Ferric Iron (mg/L)	35.8	1.69	0.75	2.99	0.83	0.58
pH	6	8	8	10	8	10
Treatment Applied	filter	NaOH aerate filter	NaOH filter	lime soda ash filter	NaOH UF	lime soda ash UF

Note: Iron in the raw leachate sample averaged approximately 150 mg/L

This is believed to be due to the complex nature of the leachate and associated interferences which affect precipitate formation and agglomeration.

Both pretreatment options were evaluated in longer term tests using a tubular test module to better simulate larger scale operation. ZENON's MF-AST tubular membranes, which had been demonstrated to be effective during the bench scale study (ZENON, 1988), were used in these tests.

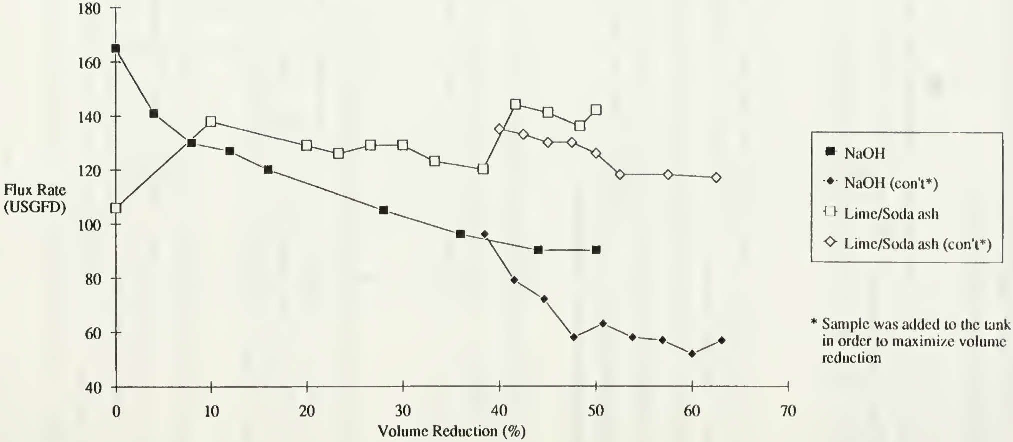
These tests were conducted to evaluate and compare microfilter performance with caustic and lime addition. Although residual iron levels were low with both pretreatments, earlier tests showed that lower flux rates were obtained with caustic compared to lime addition (ZENON 1988). Since precipitation of metals with caustic typically results in a sludge which is more difficult to dewater, longer term tests were conducted to determine the effects of sludge consistency and composition on the membrane performance.

The results of the microfiltration tests are presented in Figure 5-2 and Tables B-3 and B-4 in Appendix B. Figure 5-2 shows flux as a function of volume reduction. Tables B-3 and B-4 provide the data used to develop Figure 5-2 and the raw data collected during the stability and concentration runs.

Stability tests were conducted to expose the membrane to the feed and to allow the flux to stabilize at a constant feed concentration. The flux (after caustic addition) at the start of the run, was 489 (LMH)(288 US gfd) and fell to 280 LMH (165 US gfd) in 2 hours. With lime and soda ash addition, the flux started at 290 LMH (171 US gfd) and stabilized at 180 LMH (106 US gfd).

During concentration tests, the membrane is exposed to a constantly increasing feed concentration, since permeate is removed from the system. The concentration run begins upon completion of the stability tests, and starting fluxes were 290 and 180 LMH (171 and 106 USgfd) for the caustic and lime treatments, respectively. However, the flux from the leachate with caustic addition decreased with concentration to about 93 LMH (55 USgfd) at 70% volume reduction,

Figure 5-2
Plot of Flux vs. Volume Reduction for Lime/Soda Ash and Caustic Pre-treatment



* Sample was added to the tank, in order to maximize volume reduction

while the flux after lime and soda ash addition increased to about 203 LMH (120 USgfd) and remained at that level (on average) up to 70% volume reduction.

These results were consistent with those obtained during bench scale testing using another leachate as feed (Krug and McDougall, 1988).

Since process economics are highly dependent upon flux rate and volume reduction achievable, the lime-soda ash pretreatment option was selected for the pilot demonstration study.

5.2 System Performance

The performance of the microfiltration/reverse osmosis pilot-scale treatment system was evaluated at the Muskoka Lakes landfill site through a series of twelve tests. The pretreatment chemicals used and test conditions for each run are summarized in Table 5-2.

The membranes were initially exposed to standard reference solutions in order to establish baseline flux and conformity with manufacturers design specifications. The system was designed and operated in a batch treatment mode. Stability tests were conducted initially to establish baseline fluxes upon exposure to the feed under evaluation. A series of concentration tests were then conducted to establish performance at various concentration factors. Since volume reduction was limited by batch size as well as tank and pump configuration, several tests were conducted to treat a larger batch and thereby more closely simulate continuous operation. This was done by reducing the feed volume to a desired concentration level then adding fresh feed to top up the tank. This allowed an assessment of performance at higher concentration levels. Chemical dosages were adjusted during the course of the treatment of study to optimize performance. The final two runs were conducted under optimized treatment conditions and represent the best performance achieved during this study.

5.2.1 Microfiltration Performance

The results of microfiltration system operation as indicated by permeate rate versus time during the seven pilot test runs (#3, 5, 6, 8, 10, 11, 12) are presented graphically. Data for tests 8,

Table 5-2
Summary of Field Test Conditions

Test #	Date	Micrfiltration			Reverse Osmosis		
		Pretreatment	Operation Mode	Cleaning	Pretreatment	Operation Mode	Cleaning
1	28-Sep	none	Baseline tap water flux				
2	28-Sep				none	Baseline salt water flux ~ 2000 ppm $NaCl$ (included in run 5)	
3	3-Oct	(30g/10 gal) lime (43g/10 gal) Na_2CO_3 to pH 10	Stability at 0%, 50%, 75%, 88% for 2 h. each	detergent			
4	10-Oct	none	Baseline tap water flux low flux, insufficient cleaning	detergent			
5	10-Oct	(30g/10 gal) lime (43g/10 gal) Na_2CO_3 to pH 10	Concentrate to 90%	acid	none	Stability at 0%, 25%, 50%,75% for 1h.	acid
6 / 7	17-Oct	(30g/10 gal) lime (43g/10 gal) Na_2CO_3 to pH 10	Semi continuous testing concentrate two batches 95%	acid	none	Concentrate to 95%	acid
8	23-Oct	(30g/10 gal) lime (43g/10 gal) Na_2CO_3 to pH 10	Continuos operation, concentrate two batches to final concentration of 96%	acid	none	Concentrate to 90%	acid
10	1-Nov	(43g/10 gal) lime to pH 8	Concentrate three batches to a final concentration of 82%.	acid	none	Concentrate to 90%	acid
11	8-Nov	(43g/10 gal) lime to pH 8	Concentrate three batches to a final concentration of 75%	acid	50% (v/v) HCl to pH 6 Total acid vol 2.34 L	Concentrate to 85%	acid
12	13-Nov	(43g/10 gal) lime to pH 8	Concentrate two batches to a final concentration of 76%	acid	50% (v/v) HCl to pH 6 Total acid vol 1.83 L	Concentrate to 80% Stability at 80% for 7 h.	acid

11 and 12 are presented in Figures 5-3, 5-4, and 5-5, and illustrate the effects of various test conditions. The remaining graphs are presented in Appendix C. The operating conditions of volume reduction (VR), average trans-membrane pressure, and temperature are also presented on these graphs to show how the system permeate rates were affected by these variables.

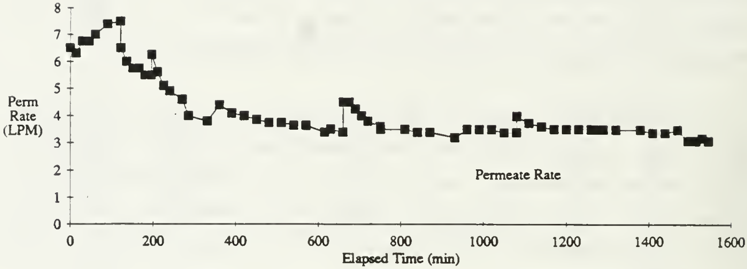
During Pilot Test #3 (Appendix C, Figure C-1), a permeate rate of 7.8 LPM was obtained with pure water at a temperature of 26°C. The permeate dropped to 5.4 LPM when the cooler (8°C) leachate feed was introduced to the system. The rate declined slightly to near 4 LPM then remained constant at that level during the remainder of the test and a concentration of the feed up to an 88% volume reduction level. The stable permeate rate of 4 LPM is equivalent to a flux of 123 LMH (73 USgfd).

The permeate rate during Pilot Test #5 (Appendix C, Figure C-2) was stable for the entire test at about 2.2 LPM. The permeate rate at the start of the test with pure water feed was only 2.5 LPM. The rate was relatively unaffected by the change to the leachate feed and concentration to a 90% volume reduction.

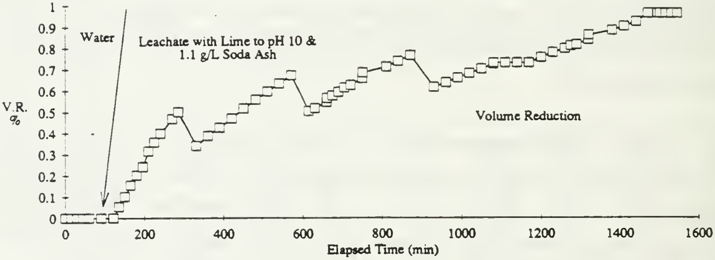
The MF membranes were cleaned with an acidic cleaner after Test #5 to remove iron and other inorganic material which may have fouled the membrane. The permeate rates obtained during the subsequent test (#6) are shown on Figure C-3. The cleaning after Test #5 was sufficient to restore flux to the levels observed with new membranes. The permeate rate declined from about 6 LPM to 4 LPM during the first 400 minutes of operation and concentration to a 90% volume reduction. The permeate rate increased to about 5 LPM when fresh feed was added to the process tank and reduced the volume reduction to 45%. The permeate rate declined over the following 500 minutes to 3 LPM or a flux of 92.5 LMH (54 USgfd).

The pure water permeate rate at the start of Test #8 (Figure 5-3) ranged from 6.2 - 7.5 LPM. When the leachate feed was introduced to the system the flux declined over about 200 minutes from 6 to about 3.5 LPM and remained stable at that level for 1200 minutes of operation and concentration to a 96% volume reduction.

Figure 5-3
Microfiltration System Operation - Pilot Test # 8



MF Volume Reduction - Pilot Run # 8



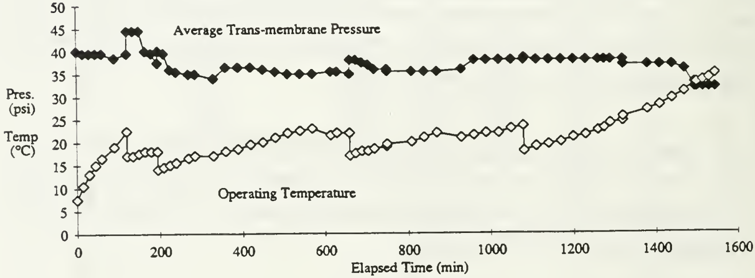


Figure 5-4
Microfiltration System Operation - Pilot Test # 11

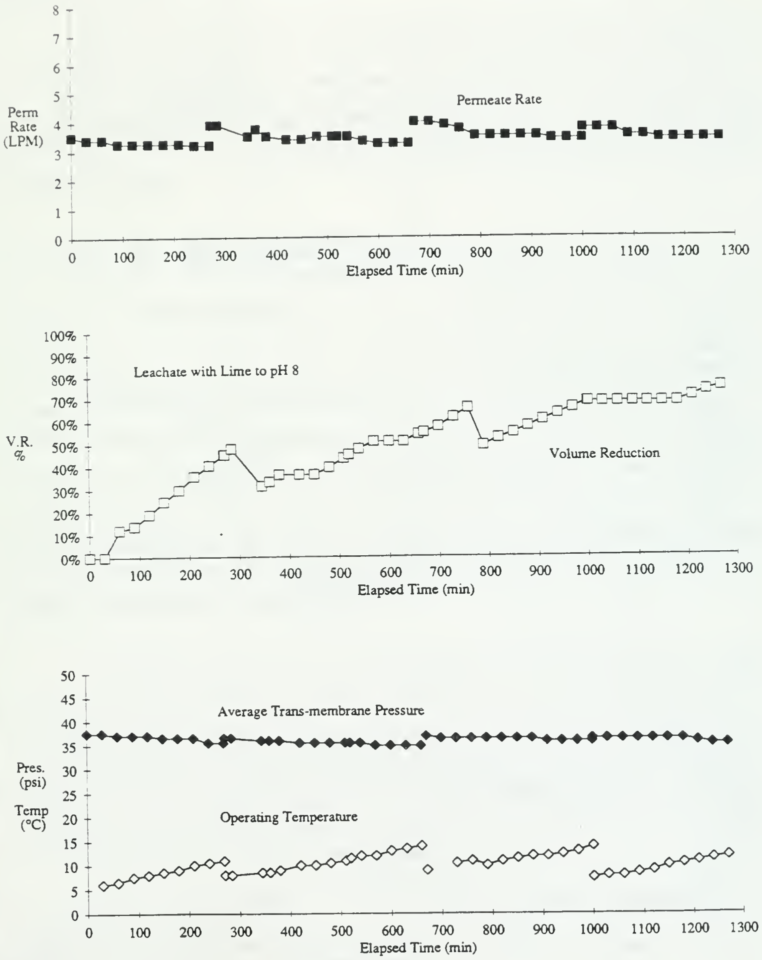
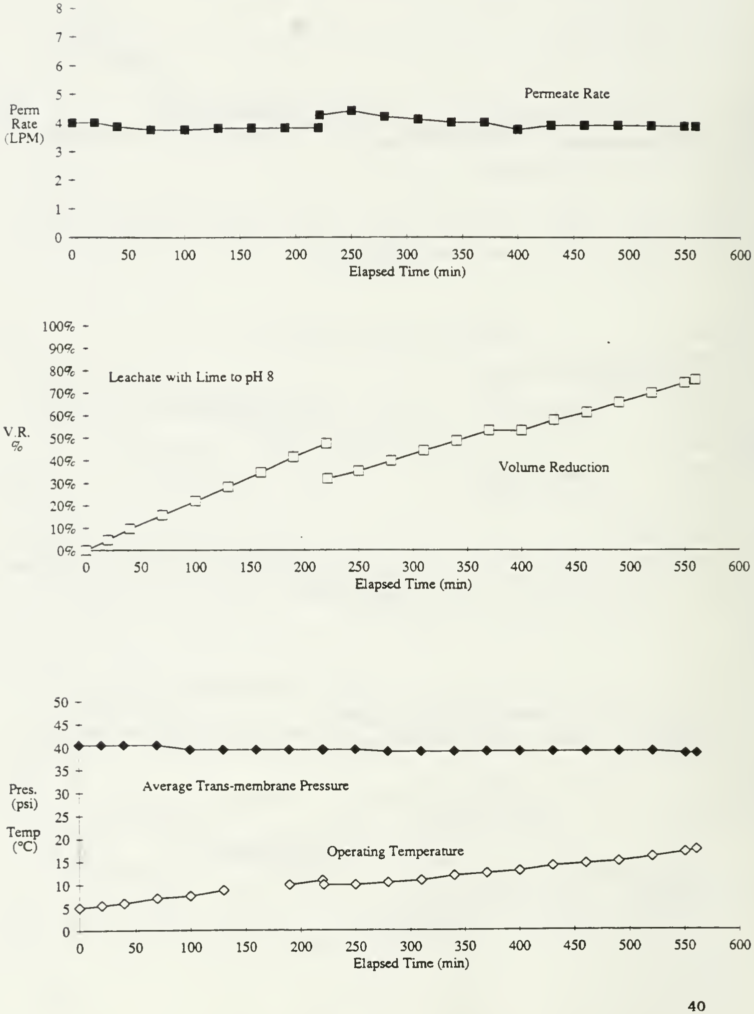


Figure 5-5
Microfiltration System Operation - Pilot Test # 12



The permeate rates during Tests # 10, 11 and 12 (Figure C-4, Figures 5-4 and 5-5), were stable between 3 and 4 LPM during concentration to 75% to 80% volume reduction.

The results of the microfiltration tests indicate that high and stable fluxes, ranging from 92 to 123 LMH (54 to 72 USgfd), can be maintained with raw leachate treated with lime or lime and soda ash and concentrated to levels as high as 96% volume reduction. As expected, the flux was affected greatly by the operating temperature but the effect of increasing volume reduction was generally quite small.

5.2.2 Reverse Osmosis Performance

The results of Reverse Osmosis (RO) system operation during the Pilot Tests (#5, 6, 8, 10, 11 and 12) are summarized graphically. Data for Tests 5, 6 and 10 are presented in Appendix D (Figures D-1 to D-3) and data for Tests 8, 10, and 12 are presented in Figures 5-6 to 5-8. As with the MF operating results, the operating conditions of volume reduction (VR) and operating temperature are presented to show how the permeate rates were affected by these variables. The graph for volume reduction also shows the type of feed being processed at any given time during the test period. The inlet pressure to the RO membranes during all RO tests was maintained at 2760 KPa or 400 psi. The RO membrane was cleaned with an acid cleaner (ZENON MC-1) after each run. The duration of the cleaning was limited to 30 - 60 minutes and was not always effective in restoring flux. A longer duration cleaning would be expected to result in a more significant improvement in flux between runs.

The initial salt water test at the start of Test #5 (Figure D-1) provides a baseline for the RO membrane performance and demonstrates the sensitivity of flux to operating temperature. The permeate rate increased from 6 LPM (flux of 48.6 LMH or 28.7 US gfd) to 8 LPM (flux of 64.9 LMH or 38.2 US gfd) as the operating temperature increased form 23°C to 35°C. Manufacture specifications for this membrane suggest that a 45% increase in flux should occur between 22°C and 35°C. The observed increase of 33% is somewhat less than expected.

After a 2 hour salt water test, the RO system was fed permeate from the microfiltration

Figure 5-6
Reverse Osmosis System Operation - Pilot Test #8

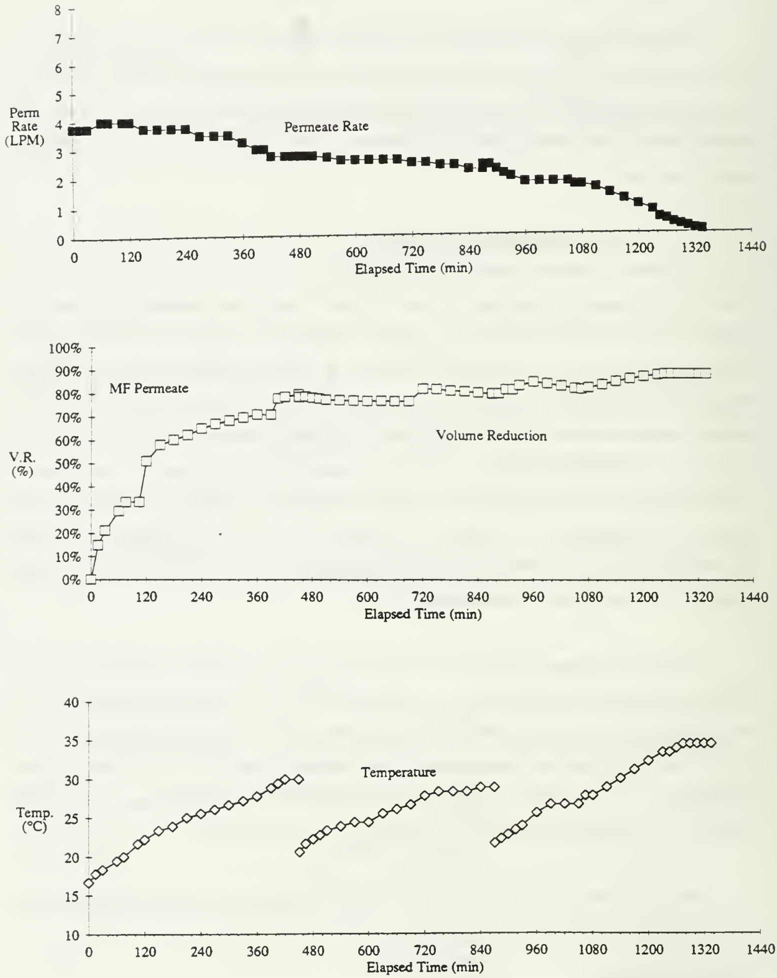


Figure 5-7
Reverse Osmosis System Operation - Pilot Test #11

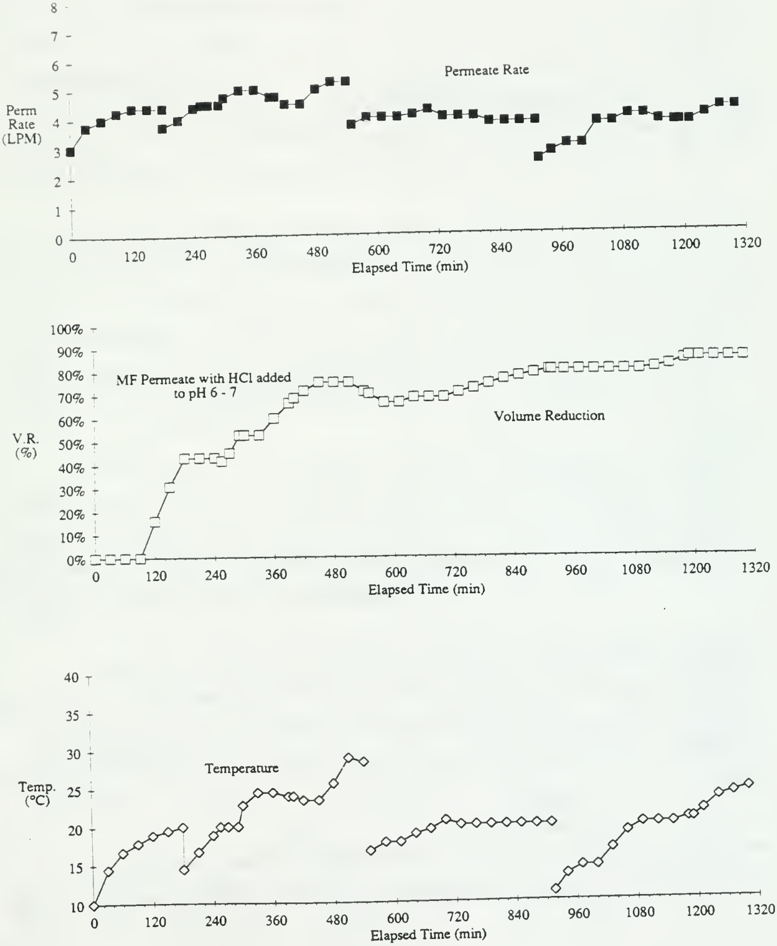
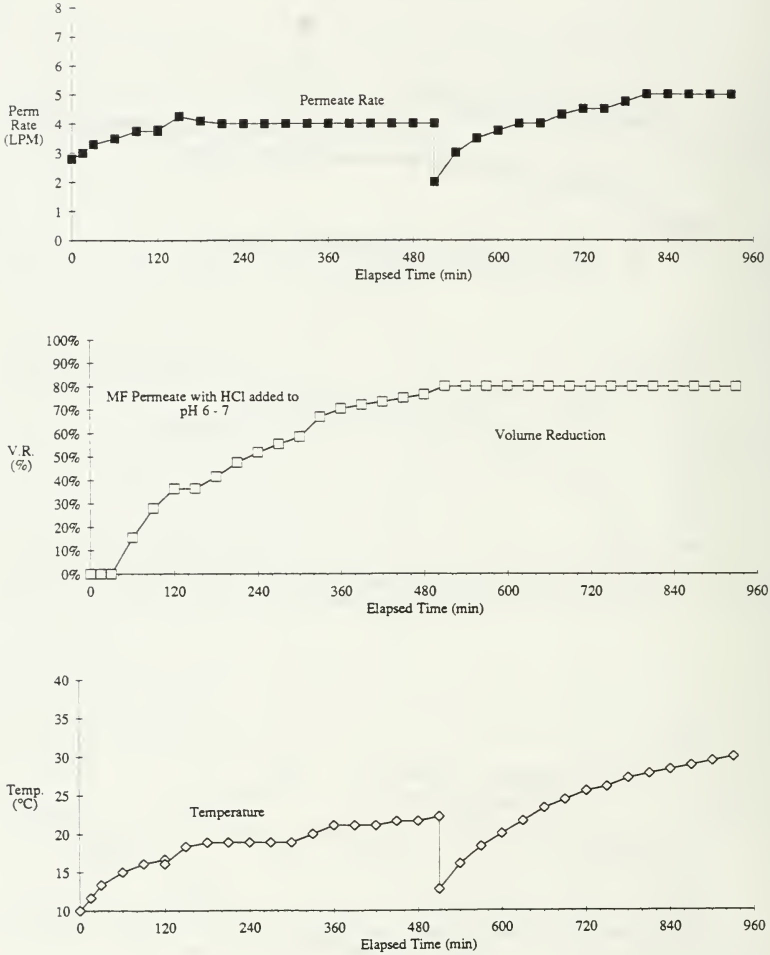


Figure 5-8
Reverse Osmosis System Operation - Pilot Test #12



system. The permeate rate was stable for 6 hours of operation, at about 5.5 LPM (flux of 44.6 LMH or 26.3 US gfd) while the volume reduction was increased to 75%. The permeate rate declined very quickly and significantly when the volume reduction reached 88%. The decline continued until almost no permeate was obtained from the membrane. As the volume reduction is increased, sparingly soluble salts of Ca, Mg and other components became more concentrated. It is believed that at some point between a 75% and 85% volume reduction the concentration of some of these salts exceeded their solubility and precipitation on the membrane began to occur. This precipitation generally causes a significant and rapid decline in membrane flux.

The permeate rate during the initial 6 hours of Test #6 (Figure D-2) was stable between 3.5 and 4 LPM as the volume reduction was increased to about 80%. The slightly lower rate relative to Test #5 is believed to be due to the lower operating temperature and some residual fouling of the membrane from operation at very high volume reductions at the end of the previous test. As in the previous test, the flux was stable up to an 80% volume reduction and then declined rapidly despite a significant increase in operating temperature.

After 400 minutes, fresh MF permeate was added to the process tank to decrease the volume reduction to 72%. The permeate rate increased with the more dilute feed in spite of a significantly lower operating temperature. The permeate rate was stable at about 3 LPM for the next 7 hours until the volume reduction was increased to above 82%. As in the previous run, the permeate rate declined rapidly at this concentration level.

The permeate rate during Test #8 (Figure 5-6) declined very slowly over the initial 14.6 hours and a concentration to an 80% VR level. The flux decline became more rapid after the VR was increased above 80%. The results suggest that some fouling of the membrane was occurring above a 70% VR level. Rapid fouling, typical of inorganic scale formation occurred above the 80% VR level.

The initial permeate rate for Test #10 (Figure D-3) was low at 2.1 LPM. It is believed that this low rate is due to insufficient cleaning of the membrane after they were severely fouled during the last part of Test #8. The permeate rate for Test #10 was initially stable then declined slowly when the volume reduction was increased above 75%. The results suggest some fouling is occurring at a volume reduction of 75% as a critical concentration of sparingly soluble salts is approached.

The initial permeate rate for Test #11 (Figure 5-7) was comparable with earlier runs suggesting that the cleaning after Test #10 was sufficient. The pH of the MF permeate feed was decreased to between 6 and 7 with HCl to decrease the tendency for $CaCO_3$ scale formation. The permeate rate (corrected to a temperature of of 20°C) during the entire 22 hour run was stable at 4 LPM (flux of 32.4 LMH or 19.1 USSgfd) while the concentration was increased to an 82% VR. The results demonstrate that pH adjustment of MF permeate is effective in allowing a stable flux to be maintained at VR levels over 80%.

The results for Test #12 (Figure 5-8) are similar to those obtained in Test #11 and support the findings that appropriate pH adjustment allows for stable permeate rates up to an 80% VR level.

5.2.3 Contaminant Removal

Table 5-3 shows a summary of the key analytical parameters and their removal during the various test runs. Complete analytical results are presented in the Appendix E. Due to an error in analytical methodology, BOD data is not available for early test runs. Table 5-4 presents the COD:BOD ratio for samples where both values are available. The ratio of COD to BOD is consistently about 2:1 for all except one RO permeate sample where the ratio is 3:1. These values are consistent with the expected ratio and suggest that the COD measurement can be used as an indicator of BOD removal for tests where only the COD analysis is available.

Figures 5-9, 5-10 and 5-11 show the removal of COD, BOD, and TOC for each of the seven pilot tests. As expected, the results demonstrate that the MF process has very little effect on the level of organics present in the leachate. The significantly higher TOC values in the MF permeate relative to the raw feed may be a result of analytical interference by the high levels of

Table 5 - 3

Summary of Analysis for Pilot MF and RO Tests

Parameter	Sample	Test Number						
		3	5	6	8	10	11	12
COD (mg/L)	Raw leachate	470	410	-	490	430	450	450
	MF Perm	440	570	-	480	420	450	440
	RO Perm	-	10	-	140	90	29	43
BOD (mg/L)	Raw leachate	-	-	-	-	-	215	-
	MF Perm	-	-	-	-	-	235	245
	RO Perm	-	-	-	-	-	15	14
TOC (mg/L)	Raw leachate	200	230	-	220	-	225	165
	MF Perm	900	360	-	275	-	238	170
	RO Perm	-	3	-	52	-	30	9
Iron (mg/L)	Raw leachate	140	150	120	155	130	160	150
	MF Perm	0.07	0.01	0.01	0.5	0.01	0.9	3
	RO Perm	0.001	0.13	0.01	0.09	0.01	0.02	0.02
Ca (mg/L)	Raw leachate	75	86	63	72	73	70	72
	MF Feed	-	-	300	-	-	270	230
	MF Perm	1.6	2.1	20	1	20	50	69
	RO Perm	-	0.8	1.8	0.6	1.8	5.9	8.9
Mg (mg/L)	Raw leachate	9.9	14	8.9	12	11	10	10
	MF Feed	-	-	150	-	-	120	100
	MF Perm	46	91	100	37	100	72	72
	RO Perm	-	0.2	19	8.2	19	5.5	5.7
Ba (mg/L)	Raw Feed	0.25	0.27	0.28	0.28	0.26	0.24	0.24
	MF Feed	-	-	0.27	-	-	0.3	0.25
	MF Perm	0.003	0.003	0.007	0.001	0.007	0.029	0.055
	RO Perm	-	0.001	0.001	0.001	0.001	0.004	0.008
Sr (mg/L)	Raw Feed	0.46	0.49	0.4	0.43	0.47	0.44	0.45
	MF Feed	-	-	0.45	-	-	0.55	0.49
	MF Perm	0.009	0.011	1.3	0.001	1.3	0.2	0.25
	RO Perm	-	0.005	0.005	0.002	0.005	0.021	0.027

Table 5 - 4

Chemical Oxygen Demand (COD) to Biochemical Oxygen Demand (BOD) Ratios

Sample	COD (mg/L)	BOD (mg/L)	COD to BOD Ratio
Feed	450	215	2.1
MF Permeate	450	235	1.9
	440	245	1.8
RO Permeate	29	15	1.9
	43	14	3.1

Figure 5-9
COD Removal in Treatment Process

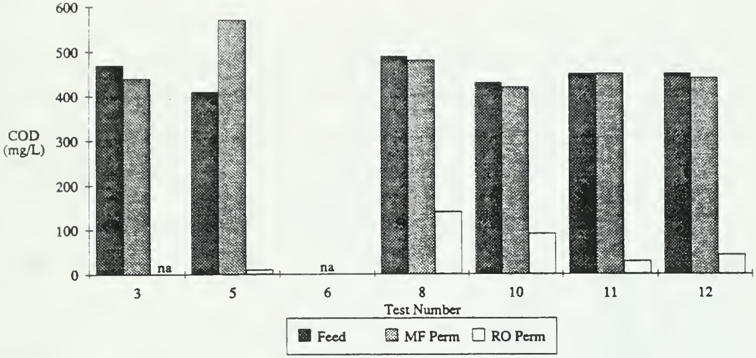


Figure 5-10
BOD Removal in Treatment Process

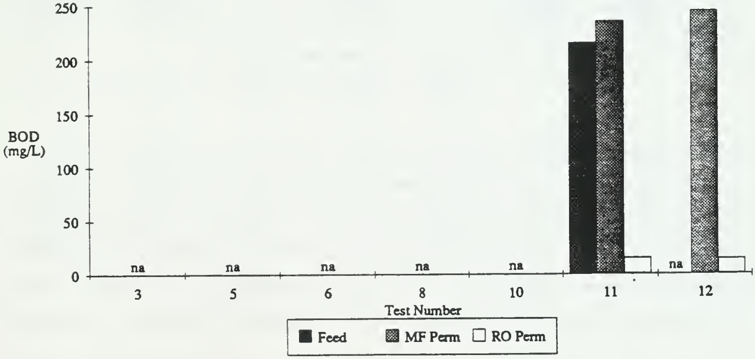
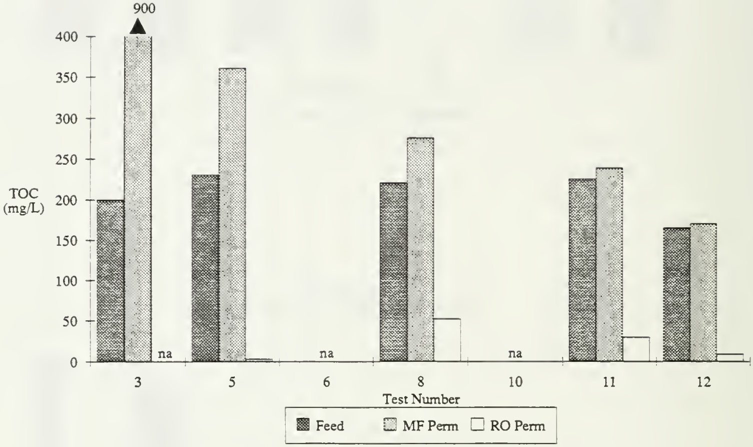


Figure 5.11
TOC Removal in Treatment Process



carbonate added to the leachate as soda ash. There is little observed increase in Test # 11 and 12 where soda ash was not used.

The results also demonstrate that the RO process is capable of removing a very high percentage of the organics present as COD, BOD, and TOC. Values for COD were reduced by 87% from an average of 470 mg/L down to an average of 62 mg/L. Values for BOD were reduced by 94% from an average of 240 mg/L down to 14 - 15 mg/L. This high quality of RO treated water satisfies the general surface discharge guideline of 25 mg/L BOD.

Figure 5-12 shows the results for the removal of iron across the treatment process. The graph presents the iron concentration on a log scale to allow feed and treated water values to be shown on the same graph. The MF process consistently removed virtually all the iron which was present the feed. Iron was reduced by 99.6% from an average of 144 mg/L down to an average of 0.64 mg/L. This consistent removal of iron will be important for the reliable operation of the subsequent RO process.

Figure 5-13 shows the removal of calcium during each of the pilot tests. During Tests # 3, 5, 6 and 8 the pH was raised to 10 with lime, and soda ash was added to provide excess carbonate to precipitate calcium as Ca CO3. During Tests # 3, 5 and 8, the calcium was reduced from an average of 78 mg/L by 98% down to an average of 1.6 mg/L. During Test # 6 the calcium was reduced from 63 mg/L down to 20 mg/L. In Tests # 10, 11 and 12 the pH was increased to 8 with lime and no soda ash was added. Without the excess carbonate, the average removal of calcium was only about 40%.

The removal of calcium is significant since the formation of calcium carbonate (Ca CO3) scale is often a limiting factor in determining the maximum recovery level possible with an RO system. The Langelier Stability Index, or LSI, provides an indication of the tendency for Ca CO3 scale formation. The index takes into account the pH, concentration of calcium, and alkalinity to calculate the potential for Ca CO3 scale formation. If the LSI is positive there exists a potential for carbonate scale formation. Another useful parameter along with the LSI is the saturation pH, or

Figure 5-12
Iron Removal in Treatment Process

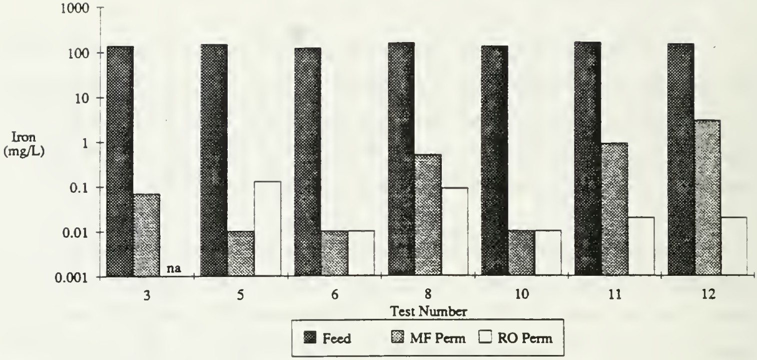
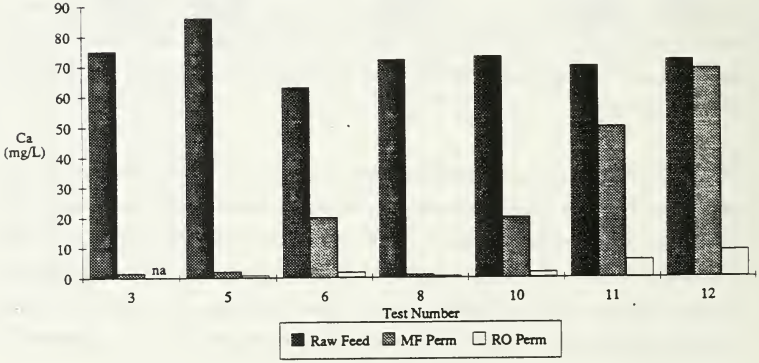


Figure 5-13
Calcium Removal in Treatment Process



the pH to which a particular water must be reduced to bring the LSI value down to zero. It is common practice to add acid to lower the pH of the feed to an RO system to prevent Ca CO3 scale formation.

Table 5-5 shows the LSI and saturate pH values calculated for the RO feeds for five of the pilot tests. Appendix E includes the summary page print out from a computer program used to calculate the LSI and saturation pH values. Alkalinity values were not measured for Tests # 5, 8, and 10 but were estimated based on the alkalinity required to balance the cations and anions in the sample. The alkalinities in Test # 5 and 8 are high as a result of the addition of soda ash (Na2 CO3) but the soda ash is effective in reducing the levels of calcium significantly.

The LSI for actual operating conditions at a 75% VR suggest a strong tendency for Ca CO3 scale formation in Test # 5, 8, and 10 where the pH was not lowered with HCl. In Tests # 11 and 12 there was only a very slight tendency for scale formation. Table 5-5 also presents the calculated LSI values for RO feeds from tests # 5, 8 and 10 if the pH were reduced to 6-5 as it was for Tests # 11 and 12. The LSI values in these cases are all less than zero and lower than those obtained in Tests # 11 and 12. Based on the results of the LSI calculations, the combination of using soda ash to reduce Ca levels in the MF process and using acid to lower the pH of the RO feed is most effective in reducing the tendency for Ca CO3 scale formation, for volume reductions above 75%.

Figure 5-14 shows the magnesium (Mg) levels in feed, MF permeate, and RO permeate for each of the pilot tests. Magnesium levels in feed were consistently about 10 mg/L. The levels in the MF permeate were much higher than in the feed as a result of Mg present in the lime added to the raw leachate. The RO is effective in removing much of the excess Mg which is present in the MF permeate.

Figures 5-15 and 5-16 show the removal of barium (Ba) and strontium (Sr). Barium is almost completely removed from the MF when the pH was raised to 10 and soda ash was added to the raw feed. The barium is likely precipitated along with the calcium. The removal of barium was not as complete in Tests # 10, 11 and 12 where the pH was raised to 8 and no soda ash was used.

Table 5 - 5

Langelier Stability Index and Saturation pH for RO Feeds

			C.F % V.R.	2 50%	4 75%	6 83.3%	8 87.5%
Test #	**Pre-treatment**	**pH**	**Parameter**				
5	Lime/Soda Ash	**10**	**LSI** **Sat. pH**	**2.77** **7.23**	**3.37** **6.63**	**3.72** **6.28**	**3.97** **6.03**
Calculated LSI	if pH adjusted to 6.5	6.5	LSI	-0.73	-0.13	0.22	0.47
8	Lime/Soda Ash	**10**	**LSI** **Sat. pH**	**1.85** **8.15**	**2.36** **7.64**	**2.66** **7.34**	**2.88** **7.12**
Calculated LSI	if pH adjusted to 6.5	6.5	LSI	-1.65	-1.14	-0.84	-0.62
10	Lime only	**8**	**LSI** **Sat. pH**	**0.9** **7.1**	**1.42** **6.58**	**1.72** **6.28**	**1.93** **6.07**
Calculated LSI	if pH adjusted to 6.5	6.5	LSI	-0.6	-0.08	0.22	0.43
11	Lime plus pH Adjustment	**6.5**	**LSI** **Sat. pH**	**-0.35** **6.85**	**0.17** **6.33**	**0.46** **6.04**	**0.67** **5.83**
12	Lime plus pH Adjustment	**6.5**	**LSI** **Sat. pH**	**-0.12** **6.62**	**0.39** **6.11**	**0.69** **5.81**	**0.9** **5.6**

C.F. - Concentration Factor
LSI - Langelier Stability Index

Sat. pH - Saturation pH
Actual run conditions are in bold

* Positive LSI values suggest potential for calcium carbonate scale formation

Figure 5-14
Magnesium Removal in Treatment Process

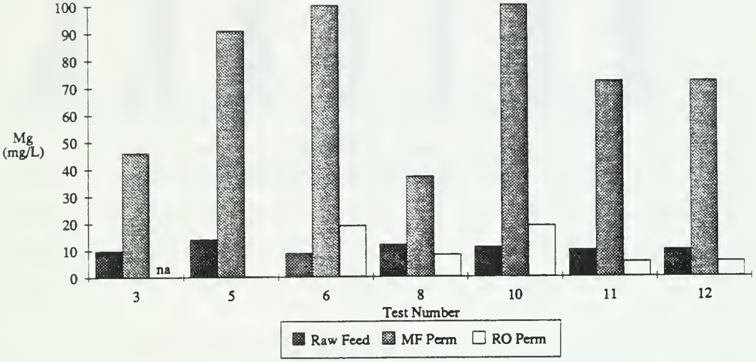


Figure 5-15
Barium Removal in Treatment Process

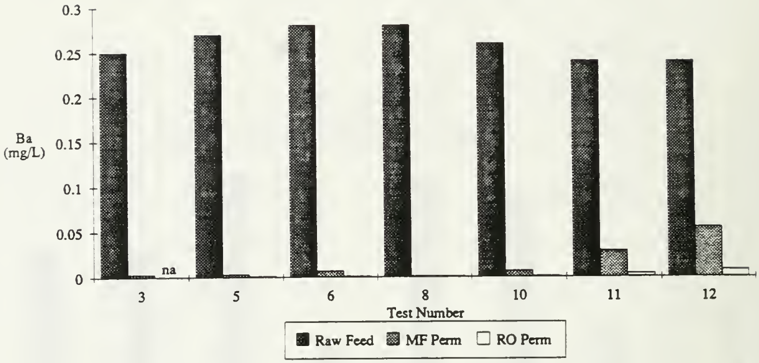
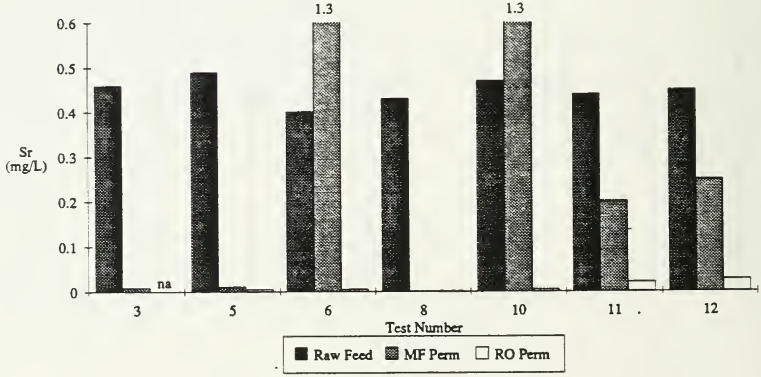


Figure 5-16
Strontium Removal in Treatment Process



Strontium was almost completely removed in Tests # 3, 5, and 8 where pH was 10 and soda ash was used. As with Ca and Ba, removals were not as significant in Tests # 11 and 12. The reasons for the very high strontium levels in the MF permeate in Tests # 6 and 10 are not known.

Table 5-6 shows the removal of EPA-624 and EPA-625 priority pollutants which were present in the raw leachate for Test #12 at levels at least 10 times higher than the minimum analytical detection limit (MDL). Figure 5-17 and 5-18 show the removals in a graphical format.

The EPA 624 contaminants all showed similar removal characteristics with some reduction (about 50%) across the MF and a further 76% reduction across the RO. The EPA-625 results are inconsistent for the removal across the MF process. Analysis showed higher levels of acenaphthene, fluorine and phenanthrene in the MF permeate than in the raw feed. It is possible that some of the contaminants present in the raw feed were lost between collection of the samples and final analysis. The removals of EPA-625 contaminants across the RO system were as follows: phenol - no removal, acenaphthene - 73%, fluorine - 87% and phenanthrene - 68%.

The analytical detection levels for the EPA 625 extractable organics (Table E-17) were greatly affected by the presence of Indole (2,3-Benzopyrrole) which was detected at approximately 100 mg/L during the scan. Indole is an aromatic compound which may be fecal in origin. Because of this exceptionally high level, the samples had to be diluted thereby influencing the analytical detection limits achievable. This interference may also account for some of the discrepancies described above.

5.2.4 Dewatering of Microfiltration Concentrate

A series of tests were carried out to assess the dewaterability of the MF concentrate. A sample of concentrate from Test #12 was evaluated using a small pilot scale plate and frame filtration unit. The microfiltration concentrate was collected at the point where 80% volume reduction, or five fold concentration was achieved. The pretreatment used for this test was the addition of lime, only, to pH 8.

Table 5 - 6

Summary of Analysis for EPA-624 and 625 Priority Pollutants

	Sample	Benzene	Toluene	Ethylbenzene
EPA-624 (µg/L)	Feed	6.9	120	22
	MF Perm	2.9	72	11
	RO Perm	0.8	14	2.8

	Sample	Phenol	Acenaphthene	Fluorene	Phenanthrene
EPA-625 (µg/L)	Feed	300	32	24	14
	MF Perm	66	88	46	24
	RO Perm	91	24	6.1	7.8

Figure 5-17
Removal of EPA-624 Priority Pollutants in Test #12

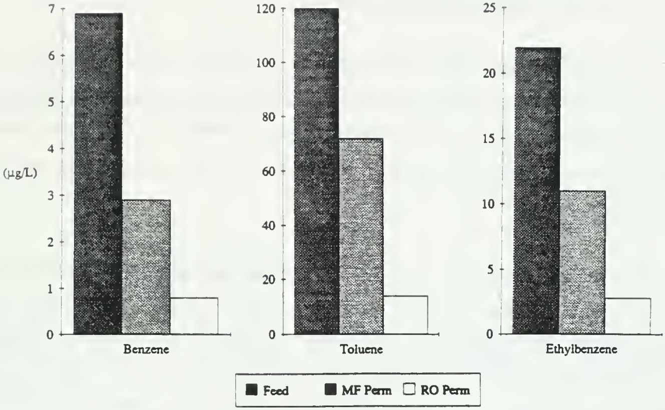
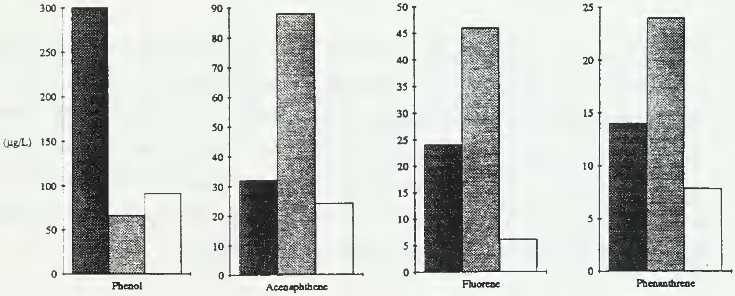


Figure 5-18
Removal of EPA-625 Priority Pollutants in Test #12



The MF concentrate as received contained 31.4 g/L of suspended solids. Settling tests were conducted, and the results shown in Table 5-7 indicate that the concentrate as received showed poor settling characteristics which usually indicates poor filterability. A flocculent aid resulted in only a minor increase in the settling rate.

In an attempt to improve the rate of filtration, filter precoat and filter aid (both diatomaceous earth) were evaluated using vacuum filtration and glass fibre filters. Results given in Table 5-8 show that the optimum dosage, defined as the point where filtration did not improve without substantial increase in dosage, was 0.01 g/cm^2 for the precoat and 56 g of filter aid per litre of concentrate slurry.

Larger scale tests were then conducted using a small pilot scale plate and frame filter. Diatomaceous earth was added both as filter precoat and filter aid at the optimum dosages given above, and the filter was operated at 52 psi. The analytical results of the filtrate are shown in Table 5-9. The filtrate was clear (4.5 NTU turbidity) and contained low levels of metals and anions. The high level of sodium is an anomaly since such levels were not encountered in the leachate and the MF does not concentrate single valence ions. The BOD was 300 mg/L and the TOC 420 mg/L and therefore the filtrate generated requires further treatment. Since the quality of filtrate was comparable to that of the MF permeate, the filtrate from a filter press could be combined with MF permeate for further treatment by the reverse osmosis system.

The moisture content of the filter cake was 58.8%. The composition of the dry filter cake was estimated based on characterization of the concentrate and filtrate, and is shown in Table 5-10. The addition of diatomaceous earth accounts for the bulk of the solids, at 63.5%. The other major constituents are calcium (6.8%), magnesium (2.2%), iron (6.4%) and their anions of hydroxide, carbonate and sulfate. The concentration of heavy metals such as cadmium, chromium, cobalt, lead, silver and zinc were either very low or were estimated to be non-detectable, and threfore disposal of the filter cake in most landfills would not pose a problem.

Table 5 - 7
Settling Test using MF Concentrate

Time (min)	Interface height (% of original height)	
	As is	With 20 drops of Aquafloc cation
0	100	100
15	99	98
25	95	92
60	89	84

Table 5 - 8
Filterability of MF Concentrate

Filter aid (g/L)	Precoat (g/cm2)	Filtration time for 50 ml sample (min)	Moisture content of cake (%)
0	0	20	75
0	0.005	19	80
0	0.01	18.5	78
0	0.016	18	
0	0.166	16.5	
0	0	20	75
64	0	11	
230	0	14.5	
48	0	13	
56	0	12	
56	0.01	11	66.5
56	0.021	11	
56	0.052	13	
56	0.104	11	

Table 5 - 9

Analysis of Filtrate

Component	MDL	Filtrate (mg/L)
pH (at 20°C)		-
Alkalinity (as CaCO3)	1	1100
Turbidity (ntu)		4.5
TOC	1	420
BOD5	5	300
TS	10	2455
TDS	10	-
TSS	10	40
Fluoride	0.1	<
Chloride	0.2	28
Nitrate (as N)	0.2	<
Bromide	0.8	<
Phosphate (as P)	0.8	<
Sulphate	1	14
Calcium	0.023	1.3
Magnesium	0.05	9.2
Sodium	0.1	550
Potassium	0.5	20
Aluminum	0.03	<
Barium	0.001	<
Beryllium	0.001	<
Boron	0.01	0.13
Cadmium	0.002	<
Chromium	0.004	0.04
Cobalt	0.01	<
Copper	0.006	<
Iron	0.01	0.43
Lead	0.02	<
Manganese	0.005	0.026
Molybdenum	0.02	0.03
Nickel	0.01	<
Phosphorus	0.06	0.17
Silicon	0.05	1
Silver	0.01	<
Strontium	0.001	0.005
Sulphur	0.06	5.2
Thalium	0.06	<
Titanium	0.01	<
Vanadium	0.005	0.036
Zinc	0.005	0.015
Zirconium	0.01	<

MDL - minimum detection limit
< - less than MDL

Table 5 - 10

Composition of Filter Cake

Component	Dry Filter Cake * (%)
Moisture Content	58.8
TOC	-
BOD5	-
TS	-
TDS	-
TSS	-
Fluoride	<
Chloride	3.4
Nitrate (as N)	<
Bromide	<
Phosphate (as P)	<
Sulphate	1.7
Calcium	6.8
Magnesium	2.2
Sodium	0.2
Potassium	0.3
Aluminum	0.0036
Barium	0.0073
Beryllium	<
Boron	0.0036
Cadmium	<
Chromium	0.0003
Cobalt	0.01
Copper	<
Iron	6.37
Lead	0.0007
Manganese	0.095
Molybdenum	<
Nickel	<
Phosphorus	0.0015
Silicon	-
Silver	<
Strontium	0.0195
Sulphur	0.0766
Thalium	<
Titanium	0.0004
Vanadium	0.0004
Zinc	0.0011
Zirconium	0.0002
Diatomaceous Earth	63.54

* Composition estimated based on characterization of MF concentrate

6.0 TECHNICAL AND ECONOMIC ASSESSMENT

Many different treatment processes may be used alone and in various combinations for treatment of landfill leachates. This chapter describes the capabilities of the MF and RO processes tested in this study as well as others which have been employed or identified as having the greatest potential for application for the treatment of landfill leachates. This chapter also includes information on the capital and operating costs of potential treatment options and a technical and economic comparison of conventional treatment processes with those evaluated in this study.

6.1 Capabilities of Potential Treatment Process Steps

6.1.1 Precipitation/Microfiltration

The results of the pilot test work demonstrate the technical capabilities of the precipitation/microfiltration process for treatment of landfill leachate. The MF process is effective in removing all suspended solids from leachates and, with the addition of lime to adjust pH, is effective in removing toxic metals down to the levels of minimum solubility. The removal of metals by MF is more reliable relative to conventional precipitation/clarification processes because the MF prevents carry-over of fine dispersed solids or pin floc. The process will remove all precipitated solids and does not depend on precipitating metal to a form which will settle easily in a clarifier. The MF process can be operated with soda ash added to the feed to reduce the level of calcium as well. This may be desirable to enhance the performance of subsequent processes such as reverse osmosis but is not likely required unless the recovery level in the RO is to be increased above 75%. The complete removal of suspended solids is also significant if these solids might interfere with subsequent downstream processes.

6.1.2 Precipitation/Clarification

Precipitation of metals with lime or caustic followed by clarification is a commonly used process for removal of toxic metals. Lime or caustic soda can be used to adjust the pH to the minimum solubility level for the metals present. The metals will come out of solution as metal hydroxides and will be settled out in the clarification process. Polymer or other chemicals are generally required to enhance the formation of large easily settleable solids. If the solids do not settle well they may be carried into the overflow of the clarifier leading to high metal concentrations in the clarifier discharge. If consistent removal of metals is required the clarifier overflow may be passed through a sand filter to remove residual solids and metals. The operation of such a process may be adversely affected by the presence of oils or other organics which can interfere with the settling of the precipitated metals.

6.1.3 Reverse Osmosis

The results of the pilot test work demonstrate the technical capabilities of reverse osmosis for treatment of landfill leachate. Table 6-1 provides a comparison of final RO quality water with Ontario and Canadian drinking water quality guidelines and surface water quality objectives. Although there are no specific guidelines for surface discharge, general effluent guidelines for secondary sewage treatment plants in Ontario are typically 25 mg/L BOD and 25 mg/L TSS (Ontario Ministry of the Environment, 1986). The RO permeate satisfied this general requirement and met water quality objectives for key inorganic parameters of concern. The RO removed 95% of the TOC present in the feed but the residual of 11 mg/L was slightly more than the 5 mg/L target for drinking water. The RO permeate satisfied requirements for key inorganic contaminants measured, in both Ontario and Canadian drinking water standards, except pH.

The feed to the RO process must be virtually free of suspended solids to prevent plugging of the thin channels in the spiral wound modules. It is often necessary to reduce the level of iron in the feed to prevent iron precipitation on the membrane. The performance of the RO system can also be enhanced by:

- reducing the levels of calcium, magnesium and other inorganic compounds which form sparingly soluble salts with carbonate or sulfate,
- lowering the pH to reduce the tendency for calcium carbonate scale formation, and
- the addition of antiscalents to prevent or reduce the effect of scale formation.

The RO process is effective in removing and concentrating most of the organic compounds found in landfill leachate. Reverse osmosis membranes will generally retain organic compounds with a molecular weight of 300 or more. The separation of lower molecular weight compounds will decline as the molecular weight decreases. In RO pilot testing the BOD was reduced from

Table 6-1

Final Permeate Quality Assessment

Component	MDL	Raw Leachate	RO (*1) Permeate (from Test #12)	Water Quality Objectives Ontario, MOE (1984)	Drinking Water (MAC)	
					Ontario, MOE (1983)	H&W, Canada (1989)
(mg/L)						
pH (@ 20 °c)		5.96	5.79	6.5 - 8.5		6.5 - 8.5
Alkalinity		180	20			
TOC	1	158	11		5 (*4)	
COD	10	430	43			
BOD5		230(*2)	14			
TDS	10	530	130		500 (*4)	500.0
TSS	10	230	<			
(mg/L)						
Bromide	0.8	<	<			
Chloride	0.2	21	35		250(*4)	250.0
Fluoride	0.1	<	<		2.4	1.5
Nitrate (as N)	0.2	<	<		1.0	45.0
Phosphate (as P)	0.8	<	<			
Sulphate	1	1.8	<		500 (*4)	500
(mg/L)						
Aluminum	0.03	0.078	<			
Barium	0.001	0.24	0.008		1.0	1.0
Beryllium	0.001	0.001	<			
Boron	0.01	0.23	0.07		5.0	5.0
Cadmium	0.002	<	<	0.0002	0.005	0.005
Calcium	0.023	72	8.9			
Chromium	0.004	0.005	<	0.1	0.05	0.05
Cobalt	0.01	0.02	<			
Copper	0.006	<	<	0.005	1.0 (*4)	1.0
Iron	0.01	130	0.02	0.3	0.3	0.3
Lead	0.02	<	<	0.005 - 0.01 (*3)	0.05	0.05
Magnesium	0.05	10	5.7			
Manganese	0.005	2.3	0.03		0.05 (*4)	0.05
Molybdenum	0.02	<	<			
Nickel	0.01	<	<	0.025		
Phosphorus	0.06	<	<	0.02		
Potassium	0.5	22	3.7			
Silicon	0.05	8.3	0.35			
Silver	0.01	<	<	0.0001	0.05	0.05
Sodium	0.1	14	2.2			270.0
Strontium	0.001	0.45	0.027			
Sulphur	0.06	1.5	0.38			
Thalium	0.06	<	<			
Titanium	0.01	0.016	<			
Vanadium	0.005	0.005	<			
Zinc	0.005	0.009	<	0.03	5 (*4)	5.0
Zirconium	0.01	<	<			
EPA-624 (µg/L)						
trans-1,2-Dichloroethane	1.1	3.8	1.4			
1,1-Dichloroethane	0.5	4.8	0.5			
1,2-Dichloroethane	0.4	1.7	0.9			
Benzene	0.2	6.9	0.8			5.0
Trichloroethane	0.3	2.4	1.5			
Toluene	0.3	120	14			-
Tetrachloroethene	0.2	1.1	0.49			
Ethylbenzene	0.3	22	2.8			
EPA-625 (µg/L)						
Phenol	1.1	300	91		2 (*4)	
Naphthalene	0.3	<	24			
Acenaphthene	0.7	32	24			
Fluorene	0.3	24	6.1			
Phenanthrene	0.3	14	7.8			

MDL - minimum detection limit
MAC - maximum acceptable Concentration
< - less than MDL
*1 - composite sample
*2- BOD data taken from previous test
*3 - Assuming alkalinity of up to 40 mg/L
*4 - Maximum desirable concentrations related to aesthetic quality. All other limits are related to health.

over 200 mg/L in the feed to less than 15 mg/L in the RO permeate. The RO process is also effective in removing virtually all residual toxic metals and in reducing the level of dissolved solids.

6.1.4 Recirculation and Spray Irrigation

Recirculation of leachate provides for a reduction in organic contaminants by providing time for natural biodegradation within the landfill itself. The landfill eventually develops an active biomass and operates in a manner similar to a fixed-film anaerobic bioreactor. Recirculation can provide a reduction in the strength of a leachate with time but does not normally provide sufficient treatment to allow for discharge without some additional treatment (Forgie, 1988).

Recirculation alone cannot provide complete treatment as there is generally a net increase in the volume of leachate with time. This excess amount of leachate must eventually be removed from the landfill. Other potential problems include odour, plugging of distribution equipment and the surface of the landfill, and negative effects on nearby vegetation.

Spray irrigation is another disposal option which has received considerable attention and can be conducted on land adjacent to the landfill site or off-site. The leachate is sprayed and dispersed over a large area of land. The volume of water present is reduced by evaporation and organics are reduced by natural biological activity and sunlight. This treatment is limited by climatic conditions as winter temperatures may result in freezing and heavy precipitation or overspraying may result in water logged conditions. Many organic contaminants may be degraded by natural biological activity and sunlight, but metals and some refractory organics may cause long term environmental damage to the area used. Spray irrigation may also be limited by serious odour problems resulting from this process (McBride et. al., 1988). Successful spray irrigation may require removal of toxic metals, including iron, and a reduction in the volume of water to be disposed of in this manner.

6.1.5 Biological Treatment

Many different biological treatment processes can and have been evaluated for treatment of landfill leachate. Forgie (1988) presents an excellent review of biological treatment methods for leachate treatment. The review suggests that biological treatment is most successful when the organics present are predominantly of a low molecular weight. Aerobic processes such as aerated lagoons, activated sludge, and rotating biological contactors (RBC) will reduce the level of organic compounds present and can be operated to reduce the level of ammonia if required. The aerobic process are generally superior to anaerobic processes in their ability to continue operating at lower temperatures and in their relatively fast establishment of active biomass. The aerobic processes are however somewhat more susceptible to inhibition by toxic metals such as Cu, Zn, and Ni. Metals present in the sludge will also limit disposal options for this residue. Aerobic processes may require addition of phosphorus, as an additional nutrient, to ensure than an active biomass is maintained. Aerobic processes will generally remove most metals but these metals will be present in the biomass sludge produced. Aerated lagoon and RBC systems are favoured over activated sludge type processes as a result of their relative ease of operation.

Anaerobic processes will also reduce the level of organic contaminants and are normally quite effective in removing metals as metal sulphides. Anaerobic processes do not normally require the addition of supplemental phosphorus and are less likely to be affected by the presence of metals. They can be slow to establish an active biomass, do not operate effectively at low temperatures, and may be prone to operating problems such as foaming and poor solids separation.

6.2 Costs for Potential Treatment Process Steps

Costs were developed for treatment steps capable of removing inorganic contaminants (precipitation/microfiltration and precipitation/clarification) and organic contaminants (RO followed by recirculation or spray irrigation and biological treatment with a rotating biological contactor). Costs (in 1990 dollars) were developed for each of the process steps to allow for a comparison of processes capable of producing similar effluent qualities, at capacities of 55, 110 and 165 m^3/day (10, 20, and 30 US gpm). These flows were chosen as typical leachate flows from a site such as the Muskoka landfill, where flow was estimated to be approximately 80-110 m^3/day or 15-20 USgpm.

6.2.1 Precipitation/Microfiltration

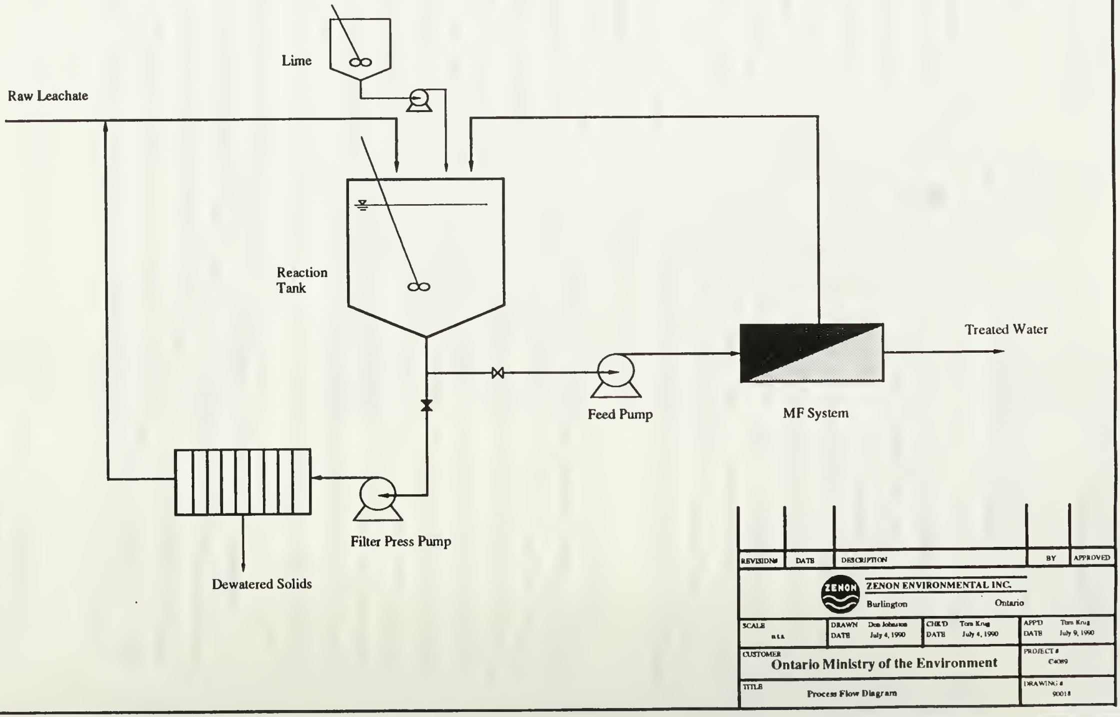
Design Basis

Cost estimates have been prepared for a leachate treatment process consisting of the addition of lime in a mix tank, microfiltration to remove precipitated metals and other suspended solids, and a plate and frame filter for dewatering the MF concentrate. In this process, the bulk of the metals and less soluble organics will be removed in the microfilter and will be concentrated in the solids from filter press. This material may be solidified or disposed of at the landfill site directly. The soluble organics and water which pass through the MF can be further treated by biological treatment, recirculation or spray irrigation. These processes may be used following the concentration of organics by RO if this will improve the operation of the process. A flow schematic for the MF process step is shown in Figure 6-1.

Equipment costs are based on manufacturers selling price for packaged skid-mounted system components. Design specifications for the MF process were obtained from experimental data generated in this work. Total installed costs for the process equipment were developed using the single factor method (Woods, 1980) to estimate the other direct and indirect costs of equipment. The installed costs include all costs associated with the facilities including foundations, instruments, piping, insulation, buildings, and services, as well as construction and field expenses, engineering and contractors fees. A factor of 2.1 times the equipment cost was used to estimate the total capital cost of the installation. This single factor was selected since the equipment costs include skid mounted prepiped equipment which required less on-site installation than standard equipment.

Operating costs, including precipitation chemicals, replacement membranes, power consumption, labour and contingencies were calculated. Details of the design specifications for the system and assumptions made in the cost analysis are presented in Appendix F. For the purpose of this cost comparison it has been assumed that the solids generated from both the precipitation/MF and precipitation/clarification process can be returned to the landfill site at a nominal charge.

Figure 6-1
Precipitation/Microfiltration Process



Treatment Process Costs

Table 6-2 shows the total capital costs and operating costs for the treatment process at three design capacities. The equipment costs show that there is some economy of scale for the larger capacity system. The capital cost of the 55 m^3/day process is \$235,000, whereas the cost of the 165 m^3/day process is \$510,900.

The total capital costs are amortized over 10 years at 11% interest. The total costs include the amortized capital costs (equipment and installation) and the operating costs for the process. The total cost for treatment per m^3 processed, as shown in Table 6-2, are \$3.89 \$3.16, and \$2.85 for the 55 m^3/day, 110 m^3/day, and 165 m^3/day process respectively.

6.2.2 Precipitation/Clarification

Design Basis

Cost estimates were prepared for a conventional precipitation/clarification process for treatment of landfill leachate. The process includes a reaction tank with provision for addition of lime to precipitate metals and a polymer to enhance the settling of precipitated material. The process also includes a clarifier, a filter press to dewater settled solids, and a sand filter to remove residual solids from the clarifier overflow. The complete process is shown in Figure 6-2.

Equipment costs are based on manufacturers selling price for equipment factored up to provide an estimate of the total capital cost.

Treatment Process Costs

Table 6-3 shows a summary of costs for the precipitation/clarification treatment step. The total costs per m^3 for treatment are slightly less than for the equivalent size precipitation/microfiltration process.

TABLE 6-2

Cost Summary for Precipitation / Microfiltration

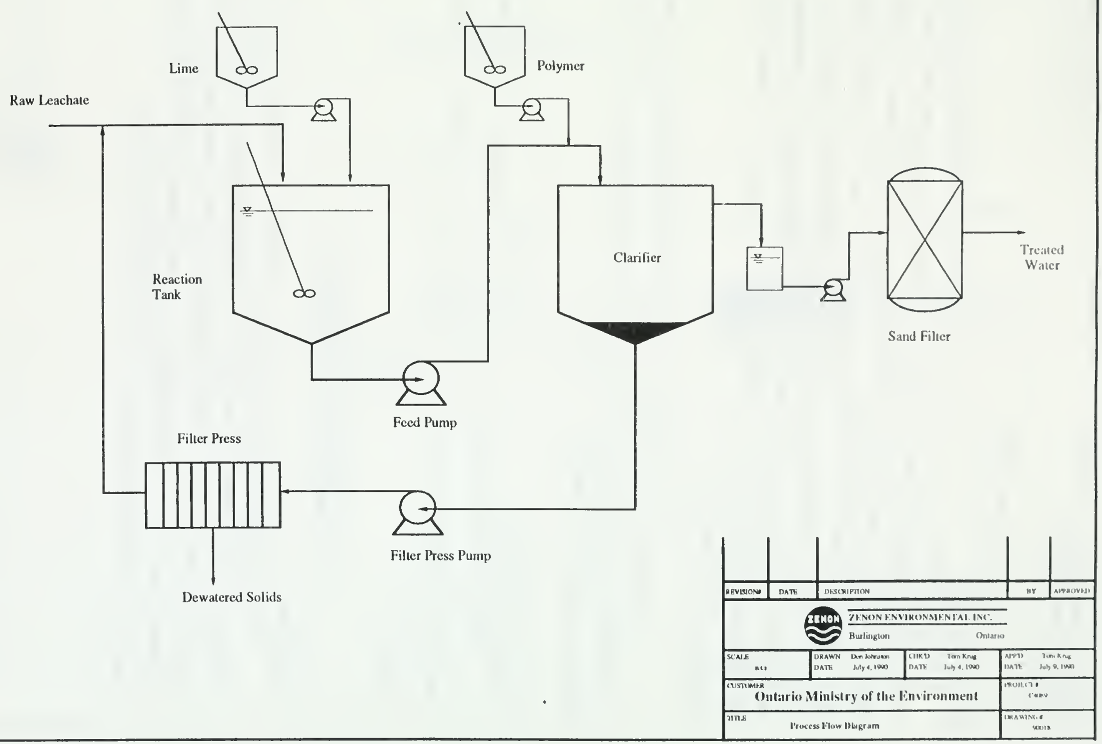
Capacity (liters/day)	55,000	110,000	165,000
Capacity (US gpm)	10	20	30
TOTAL CAPITAL COST	$236,000	$362,000	$511,000
YEARLY OPERATING COSTS	$38,000	$65,000	$85,000
TOTAL YEARLY COSTS	$78,000	$127,000	$172,000
Cost per 1,000 liters	$3.89	$3.16	$2.85

TABLE 6-3

Cost Summary for Precipitation / Clarification

Capacity (liters/day)	55,000	110,000	165,000
Capacity (US gpm)	10	20	30
TOTAL CAPITAL COST	$144,000	$170,000	$212,000
YEARLY OPERATING COSTS	$29,000	$39,000	$50,000
TOTAL YEARLY COSTS	$54,000	$68,000	$86,000
Cost per 1,000 liters	$2.68	$1.70	$1.43

Figure 6-2
Precipitation/Clarification Process



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ZENON ENVIRONMENTAL INC.
Burlington Ontario

SCALE n.t.s	DRAWN Don Johnston DATE July 4, 1990	CHK'D Tom Krug DATE July 4, 1990	APP'D Tom Krug DATE July 9, 1990

CUSTOMER Ontario Ministry of the Environment
PROJECT # [illegible]
TITLE Process Flow Diagram
DRAWING # 90018

6.2.3 Reverse Osmosis

Design Basis

Cost estimates have been prepared for the reverse osmosis (RO) portion of a leachate treatment process (Figure 6-3) to treat leachate water which has already been treated to remove metals and suspended solids in a microfiltration process. In the RO process, the residual soluble organics are concentrated in 25% of the original flow of water. This stream containing concentrated organic contaminants may be disposed of by spray irrigation, recirculation, or be trucked off to a municipal waste water treatment plant. The results of pilot test work conducted as part of this study suggest that the treated water from the RO process will be suitable for direct discharge to a local watercourse.

Equipment costs were developed for the RO process to match the capacities evaluated for the MF process. Details of the specifications for the system and assumptions made in the cost analysis are presented in Appendix F.

Treatment Process Costs

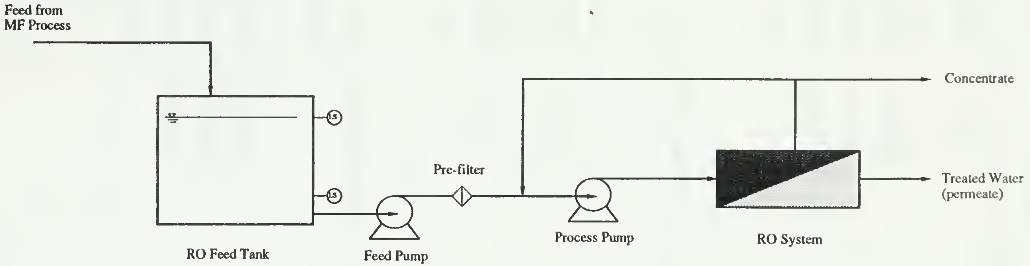
Table 6-4 shows a summary of the costs for the RO treatment step. The total treatment costs for the 55 m^3/day, 110 m^3/day, and 165 m^3/day processes are \$1.97 per m^3, \$1.55 per m^3, and \$1.30 per m^3.

6.2.4 Recirculation and Spray Irrigation

Design Basis

Processes for recirculation to the landfill site and spray irrigation involve very similar equipment. Both processes require leachate storage, a distribution pump, and a distribution system as shown in Figure 6-4. Cost estimates were developed for such systems capable of storing and distributing leachate which has been treated to remove metals and suspended solids and has been concentrated to 25% of its original volume (ie a 75% VR in the RO process).

Figure 6-3
Reverse Osmosis Process



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CUSTOMER
Ontario Ministry of the Environment

PROJECT #
C4099

TITLE
Process Flow Diagram

DRAWING #
90018

TABLE 6-4

Cost Summary for Reverse Osmosis

Capacity (liters/day)	55,000	110,000	165,000
Capacity (US gpm)	10	20	30
TOTAL CAPITAL COST	$82,000	$123,000	$155,000
YEARLY OPERATING COSTS	$26,000	$41,000	$52,000
TOTAL YEARLY COSTS	$39,500	$62,000	$78,500
Cost per 1,000 liters	$1.97	$1.55	$1.30

TABLE 6-5

Cost Summary for Recirculation and Irrigation

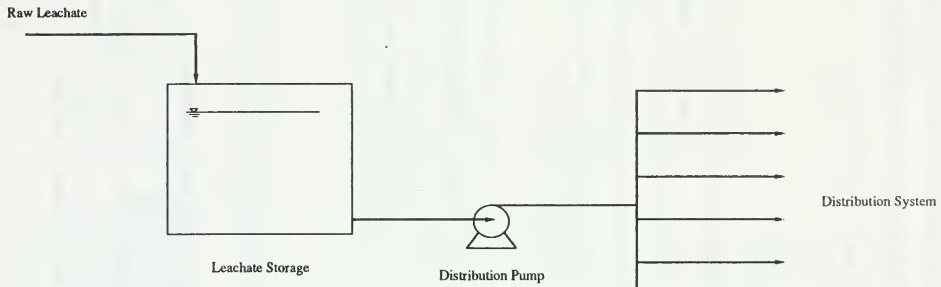
Capacity (liters/day)	55,000	110,000	165,000
Capacity (US gpm)	10	20	30
TOTAL CAPITAL COST	$26,000	$36,400	$45,500
YEARLY OPERATING COSTS	$13,000	$18,000	$22,000
TOTAL YEARLY COSTS	$18,000	$24,000	$30,000
Cost per 1,000 liters	$0.88	$0.60	$0.50

TABLE 6-6

Cost Summary for Rotating Biological Contactor

Capacity (liters/day)	55,000	110,000	165,000
Capacity (US gpm)	10	20	30
TOTAL CAPITAL COST	$260,000	$351,000	$455,000
YEARLY OPERATING COSTS	$34,500	$46,500	$58,500
TOTAL YEARLY COSTS	$79,000	$106,000	$136,000
Cost per 1,000 liters	$3.93	$2.64	$2.26

Figure 6-4
Recirculation or Irrigation Process



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CUSTOMER	PROJECT #
Ontario Ministry of the Environment	C4009

TITLE	DRAWING #
Process Flow diagram	90018

Treatment Process Cost

Table 6-5 shows a summary of capital and operating costs for the recirculation treatment step. The total costs for recirculation or spray irrigation for the 55 m^3/day, 110 m^3/day and 165 m^3/day processes are \$0.88 per m^3, \$0.60 per m^3 and \$0.50 per m^3.

6.2.5 Biological Treatment

Design Basis

A rotating biological contactor (RBC) is a biological treatment system which consists of a series of circular disks rotating partially submerged in a wastewater. Biological solids attach themselves to the surfaces of the disks and are contacted alternately with air and wastewater as the disks rotate. Organic contaminants are degraded by the biological solids as they contact the wastewater. Excess biological solids eventually slough off the disks and are removed from the wastewater in a subsequent clarification step (Metcalf and Eddy, 1972).

Cost estimates were prepared for three sizes of rotating biological contactor (RBC) systems which provide for biodegradation of many of the organic compounds present in the leachate. The components of the RBC system are shown in Figure 6-5. The systems include prepackaged systems with a primary clarifier, RBC unit, and a final clarification step. The biological solids generated will be disposed of by returning them to the landfill site at a nominal cost.

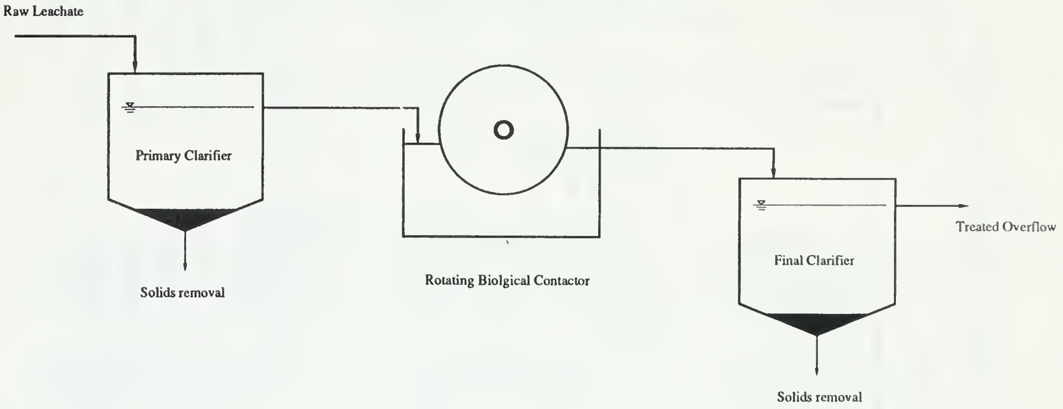
Treatment Process Costs

Table 6-6 shows a summary of capital and operating costs for the RBC treatment step.

6.3 Evaluation of Complete Treatment Processes

The individual treatment steps evaluated in Sections 6.1 and 6.2 can be used in a variety of combinations to obtain complete treatment processes which provide similar treatment objectives. Three different process schematics were considered, and these are summarized in Figure 6-6. The overall costs for each process are presented in Tables 6-7, 6-8, and 6-9. The complete processes involve:

Figure 6-5
Rotating Biological Contactor



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TITLE Process Flow Diagram			DRAWING # 90018

Figure 6-6

Treatment Combinations Considered
In Cost Assessment

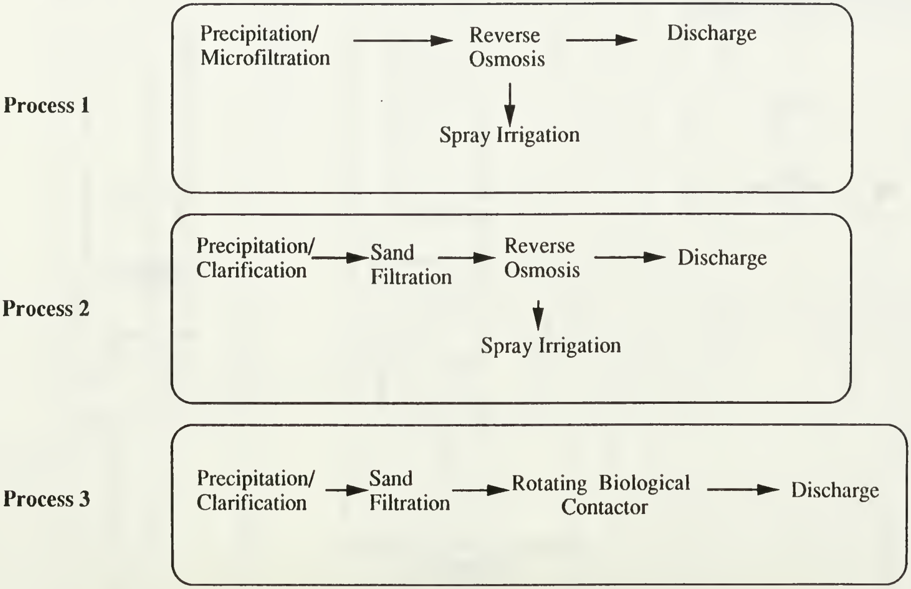


TABLE 6-7

Cost Summary for Precipitation/Microfiltration Followed by RO and Recirculation

Capacity (liters/day)	55,000	110,000	165,000
Capacity (US gpm)	10	20	30
TOTAL CAPITAL COST	$344,000	$521,400	$711,500
YEARLY OPERATING COSTS	$77,000	$124,000	$159,000
TOTAL YEARLY COSTS	$135,500	$213,000	$280,500
Cost per 1,000 liters	$6.75	$5.31	$4.66

TABLE 6-8

Cost Summary for Precipitation/Clarification Followed by RO and Recirculation

Capacity (liters/day)	55,000	110,000	165,000
Capacity (US gpm)	10	20	30
TOTAL CAPITAL COST	$252,000	$329,400	$412,500
YEARLY OPERATING COSTS	$68,000	$98,000	$124,000
TOTAL YEARLY COSTS	$111,500	$154,000	$194,500
Cost per 1,000 liters	$5.55	$3.84	$3.23

TABLE 6-9

Cost Summary for Precipitation/Clarification Followed by Rotating Biological Contactor

Capacity (liters/day)	55,000	110,000	165,000
Capacity (US gpm)	10	20	30
TOTAL CAPITAL COST	$404,000	$521,000	$667,000
YEARLY OPERATING COSTS	$63,500	$85,500	$108,500
TOTAL YEARLY COSTS	$133,000	$174,000	$222,000
Cost per 1,000 liters	$6.63	$4.33	$3.69

1) precipitation/microfiltration for metals removal followed by reverse osmosis to reduce the volume of leachate water and finally by irrigation of the concentrated organic stream for final disposal,
2) precipitation/clarification and sand filtration for metals removal followed by RO and irrigation, and
3) precipitation/clarification and sand filtration for metals removal followed by RBC treatment to degrade the organic contaminants present.

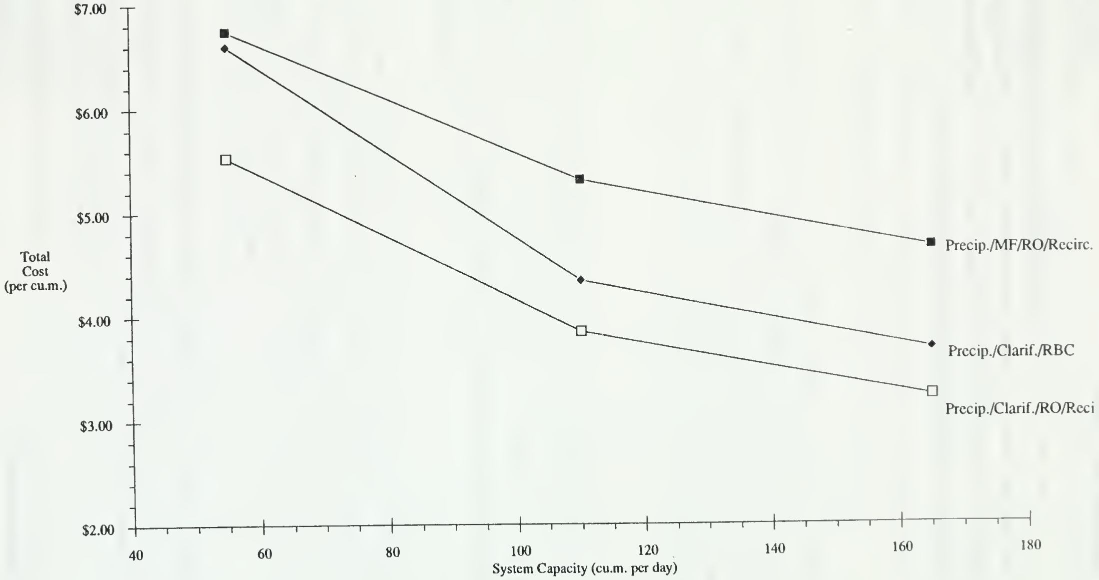
The cost comparison of the three treatment trains is illustrated in Figure 6-7 and indicates that the cost for precipitation/MF process are somewhat higher than for conventional precipitation/clarification for removal of metals and suspended solids. However, MF process may be be cost competitive in the near future if:

- the capacity performance or flux of the MF membranes can be improved,
- the cost for the membranes themselves can be reduced, or
- non cost issues such as assured removal of all suspended solids dominate the evaluation.

The costs for a complete treatment process using conventional precipitation for metals and solids removal followed by RO and recirculation compare favourably with the costs for precipitation followed by biological treatment. The costs per m^3 for the 110 m^3/day process are $3.85 for clarification/RO/Recirculation and $4.34 for clarification/RBC treatment.

The RO/recirculation process can provide a cost effective alternative to biological treatment at sites where the limitations to recirculation or spray irrigation had been excessive hydraulic loading or the effect of toxic metals on vegetation. The RO/recirculation process has the advantage over biological treatment that it can be started up quickly and does not require establishment of an acclimated microbial population. The process can also provide a method of reducing the volumes of leachate which need to be shipped to a treatment plant if this is the only alternative available. The potential cost savings relative to shipping unconcentrated leachate will vary considerably with the distance to a suitable sewage treatment plant.

Figure 6-7
Total Costs for Different Treatment Processes



This test work was conducted on leachate with a low level of organic contamination relative to many leachate waters. The results demonstrate the feasibility of the RO process in treating dilute leachates. Additional pilot testing with higher strength leachate would be required to determine the applicability of the RO process in treating these leachate streams.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Field testing of a membrane based treatment system incorporating precipitation/ microfiltration and reverse osmosis was undertaken at a landfill site in Ontario to evaluate the technical and economic effectiveness of a membrane-based process for treatment of landfill leachate. The following conclusions are made based on the results of the field program:

- The precipitation/microfiltration (MF) and reverse osmosis (RO) process was successful in achieving surface water quality and drinking water quality objectives for key inorganic parameters measured. Although there are no general guidelines for surface discharge quality in Ontario, the final permeate achieved general effluent criteria for secondary sewage treatment plants as measured by BOD and TSS, and was well below criteria for discharge to sewer.

- The microfiltration field tests demonstrated that stable flux rates ranging from 92 to 132 LMH (54 to 72 US gfd) can be maintained using leachate pretreated with lime alone or lime in combination with soda ash, even at volume reductions as high as 96%. These flux rates are somewhat lower than are normally obtained in MF applications for treatment of metal containing wastewaters.

- Inorganic parameters were reduced from 50% to 99.9% by the precipitation/MF process. Iron, in particular was reduced by 99.6%, from an average of 144 mg/L in the feed to an average of 0.64 mg/L in the MF permeate. The consistent removal of iron is important to prevent fouling of the downstream RO operation. As expected, the MF process had little or no effect on removal of organic parameters.

- The MF permeate was further treated by reverse osmosis (RO). The RO flux was shown to be stable at 32 LMH (19 US gfd) at volume reductions over 80% following adjustment of the MF permeate to pH 6-7. This flux rate is very close to that typically obtained for reverse osmosis in pure water applications.

- The reverse osmosis process was successful in removing a high percentage of the organics, present as COD, BOD and TOC, from the MF permeate. The BOD was reduced by 94%, from approximately 240 mg/L in the feed to 15 mg/L in the permeate. The RO process was also effective in removing virtually all residual toxic metals and in reducing the level of dissolved solids.

- The combination of lime pretreatment prior to microfiltration and acidification prior to reverse osmosis is the most effective option for allowing RO volume reductions up to 75%. If volume reductions greater than 75% are required, lime pretreatment with addition of soda ash can be used in the MF to remove calcium and reduce calcium carbonate scale formation on the RO membranes. Acidification of the MF permeate prior to the RO is needed to maximize overall system performance.

- Some reduction in trace volatile organic contaminants (about 50%) was observed in the MF process, with a further 76% reduction in the RO process.

- For metals and suspended solids removal only, a cost assessment indicated that the costs for the precipitation/MF process are somewhat higher than conventional precipitation/ clarification.

- For organic removal in a relatively dilute leachate such as this, reverse osmosis was shown to be about half the cost of treatment using rotating biological contactors (RBC'S) for the same flowrates.

- For removal of both metals and organics, the cost of the precipitation MF/RO process tested during this study was essentially equivalent to conventional treatment incorporating precipitation/clarification followed by biological treatment in the form of an RBC, for low flowrates (based on 55,000 litres per day or 10 US gpm). A treatment process using conventional precipitation for metals removal followed by reverse osmosis and recirculation of concentrated organics was the least expensive of three alternatives considered, and compares favourably with the costs for conventional precipitation followed by biological treatment using an RBC. The membrane based processes may offer further advantages in consistency, high quality of final effluent, and portability.

7.2 Recommendations

Based on the results of the field study, the following recommendations are made:

- A treatment process incorporating conventional precipitation and reverse osmosis can provide a cost-effective alternative to biological treatment for relatively low strength landfill leachates, at sites where technical and regulatory criteria allow for the organic concentrate can be disposed on site by recirculation or land irrigation, or where the volume of leachate must be reduced for off-site disposal. The membrane-based process may be particularly suitable for application at sites where recirculation or spray irrigation practices are limited by excessive hydraulic loading or toxic metals, or where immediate start-up of a treatment process is required.

- The conventional precipitation /RO/ recirculation process has proven technically feasible and cost competitive with conventional biological processes and should be considered for application as a permanent treatment system at sites meeting the criteria described above. For low flowrates, a process incorporating microfiltration instead of conventional clarification may offer both technical and economic advantages, depending on site specific considerations.

- Although the cost assessment indicated that the precipitation/MF and RO process was more expensive at the higher flow rates than the alternative processes considered, the system offers process advantages in some applications where non-costs issues such as assured removal of suspended solids is required, where space is of concern, or where a portable or temporary system is required. The precipitation/MF system would be more cost competitive if the membrane flux could be improved or membrane costs could be reduced. New membrane formulations with improved flux rates are continually being developed by various manufacturers and are expected to significantly improve process economics.

- A process incorporating reverse osmosis should also be considered at sites where untreated leachate is being hauled off-site for disposal, since a significantly smaller quantity of organic concentrate, with no metal concentration, would be generated. The cost advantages of concentrating the leachate would increase as fees for transportation and off-site disposal increase.

- Reverse osmosis has been shown effective as a polishing step for leachate treatment, and may be applied in combination with various unit processes. In particular, RO would be suitable for removal of residual TDS in partially treated leachates, as well as concentrating residual organics, and would assure production of a high quality effluent.

- This testing program was conducted on a relatively dilute landfill leachate. Application of the membrane based process to higher strength leachates may result in lower volume reductions achieveable or poorer effluent qualities for equivalent recoveries. Additional testing would be necessary to evaluate the technical performance and cost effectiveness of a membrane based process for the treatment of higher strength landfill leachates.

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Appendix A

Analytical Test Methods

MISA METHOD SUMMARY SHEET: METHOD CODE ZE055A - TSS (MISA Analytical Test Group 8) page 1 of 1

Preparation Date: January 1988, revised July 1989 by : A.K.Young

METHOD DESCRIPTION:

Principle of the method- A well-mixed sample is filtered through a weighed standard glass fiber filter and the residue retained on the filter is dried to a constant weight at 103 to 105°C. The increase in weight of the filter represents the total suspended solids.

Analytical procedure-

1. Weigh the of glass fiber filter disk and place in a drying dish.
2. Place filter in vacuum filtration apparatus. Rinse the filter with 20 mL of RO water.
3. Transfer the well-mixed and measured sample (50-200 mL depending on particulates) through the filter.
4. Wash with 10 mL RO water three times. Allow complete drainage between washings by continuous suction.
5. Dry the filter disk in an oven at 103 to 105°C for at least 1 h. Cool in a desiccator and weigh.
6. Repeat cycle of drying, cooling, dessicating and weighing until a constant weight is obtained, or until weight loss is less than 4% of the previous weight or 0.5 mg, whichever is less.
7. Total suspended solids is expressed as mg solids per liter of sample.
8. Replace sample with 50- 200 mL RO water (same volume as the sample used) and follow the same procedures. The sample is reported as method blank.

reference : Standard Methods for the Examination of Water and Wastewater. 16th edition, pp96-97, 1985.

MISA TEST LIST FOR THIS METHOD CODE : reporting units mg/L

MOE TEST CODE (see MISA List) (or test name)	SMALLEST REPORTING INCREMENT	METHOD DETECTION LIMIT	* Water	HIGH CALIB'N
RSP	0.1	4.15	RO Water	Not Applicable

* water used to determine MDL: I

METHOD SUMMARY SHEET: METHOD CODE ZE340A - TDS

Preparation Date: June 1989 by : A.K.Young

METHOD DESCRIPTION:

Principle of the method- A well-mixed sample is filtered through a standard glass fiber filter and the filtrate is evaporated to dryness in a weighed dish and dried to a constant weight at 180°C. The increase in dish weight represents the total dissolved solids.

Analytical procedure-

1. Heat clean beaker (150 mL) at 180°C for 1 h in an oven. Store in desiccator until needed. Weigh immediately before use.
2. Place glass-fiber filter disk in vacuum filtration apparatus. Rinse the filter with 3x20 mL of RO water. Continue suction to remove all traces of water. Discard washings.
3. Transfer the well-mixed and measured sample (50-200 mL depending on particulates) through the filter.
4. Wash the disk with 10 mL RO water three times. Allow complete drainage between washings by continuous suction. Apply suction for 3 more min. after the filtration is complete.
5. Transfer the filtrate into the heated and weighed beaker and evaporate to drynes in an oven at 180°C (approx. 1 h.) Cool in a desiccator and weigh.
6. Repeat cycle of drying, cooling, dessicating and weighing until a constant weight is obtained, or until weight loss is less than 4% of the previous weight or 0.5 mg, whichever is less.
7. Total dissolved solids is expressed as mg solids per liter of sample.
8. Replace sample with 50- 200 mL RO water (same volume as the sample used) and follow the same procedures. The sample is reported as method blank.

ference : Standard Methods for the Examination of Water and Wastewater. 16th edition, pp95-96, 1985.

REPORTING UNITS FOR THIS METHOD CODE : mg/L

TEST ANALYTE	SMALLEST REPORTING INCREMENT	METHOD DETECTION LIMIT	* Water	HIGH CALIB'N STANDARD
TDS	0.2	1	RO Water	Not Applicable

* water used to determine MDL: Revbersed-Osmosis Deionized Water produced by Zenon

METHOD SUMMARY SHEET:METHOD CODE ZE305A- Alkalinity

Preparation Date: June 1989 by : A.K.Young

METHOD DESCRIPTION:

Principle of the method- Hydroxyl ions present in a sample as a result of dissociation or hydrolysis of solutes react with additions of standard acid. Alkalinity of the sample is automatically calculated and depends on the end-point pH used. A multi-Dosimat 655 equiped with a motor-driven piston burette with microprocessor -control unit is used for the determination of alkalinity.

Analytical procedure-

Preparation of standards/titrant
Stock standard (as1000 ppm $CaCO_3$)- dissolve 1.06 g of Na_2CO_3 in 1 L of RO water.
Working standard (as100 ppm $CaCO_3$)- dilute 10 mL of the stock standrad to 100 mL with RO water. This standard is prepared freshly.
Stock titrant solution (0.2 N H_2SO_4)-dilute 11.1 mL of conc. H_2SO_4 to 2 L with RO water.
Working titrant solution(0.02 N H_2SO_4)-dilute 100 mL of the stock titrant solution to 1L with RO water

The instrument is left on all time. Clean the electrode and empty the titrant line. Ensure the working titrant solution is sufficient.

Sample preparation is not required for water samples. Sample is diluted , if necessary, to ensure its alkalinity is within the working range.

1.Calibrate the Metrohm Dosimat 655 with 2 buffers (pH= 6 & 10).
2.Analyze 2 buffer solution (pH= 4 &7). The readings should be within 5% of the expected pH values.
3.Calibrate the instrument twice with 100 mL of working standard (100 ppm) .
4. Analyze100 mL of RO water. The alkalinity of the RO water should be between -1.2 to 1.6 ppm.
5 Analyze100 mL of tap water. The alkalinity of the tap water should be between 89 to 110 ppm.
6. Proceed with the sample analysis when above mentioned criteria are met.
7. Alkalinity , $CaCO_3$(mg/L), of the sample is automatically calculated and recorded on the tape.

reference : Standard Methods for the examination of Water and Wastewater. 16th edition, pp269-273, 1985.

MISA TEST LIST FOR THIS METHOD CODE : reporting units mg/L

MOE TEST CODE	SMALLEST REPORTING INCREMENT	METHOD DETECTION LIMIT	* Water	HIGH CALIB'N
Alkalinity	0.2	1	RO	100

* water used to determine MDL: I

MISA METHOD SUMMARY SHEET : METHOD CODE ZE075B - COD (MISA Analytical Test Group 1) page 1 of 1

Preparation Date: July,1989 by : A.K.Young

METHOD DESCRIPTION:

Principle of the method- This method is based on the ability of potassium dichlormate to oxidize organic compounds under acidic conditions. Sample is heated with acidic potassium dichromate and the organic matter in the sam reduces the chromium (VI) to chromium (III). The production of chromium (III) is measured colorimetrically at 600 nm and is directly proportional to the COD in the sample.

Analytical procedure-

Standard Preparatiuon:

Stock standard (1000 ppm KHP) - dissolve 0.85 g of potassium hydrogen phthalate in 1 L of RO wate

Working standard - prepare freshly

100 ppm KHP- dilute 0.1 mL of the stock standard to 10 mL with RO water.

200 ppm KHP- dilute 0.2 mL of the stock standard to 10 mL with RO water.

300 ppm KHP- dilute 0.3 mL of the stock standard to10 mL with RO water.

400 ppm KHP- dilute 0.4 mL of the stock standard to 10 mL with RO water.

500 ppm KHP- dilute 0.5 mL of the stock standard to 10 mL with RO water.

Reagent Preparation:

FAS(0.25 M) titrant- dissolve 98 g $Fe(NH_4)_2 (SO_4)_2 .6 H_2O$ in 900 mL of RO water; add 20 mL of conc. H_2SO_4, cool, and dilute to 1L with RO water.

Sulfuric acid reagent- dissolve 22g of Ag_2SO_4 in 4.25 Kg of conc. H_2SO_4.

$K_2Cr_2O_7$ (0.0417M)-dissolve 10.216 g of $K_2Cr_2O_7$,and 33.3 g $HgSO_4$ in 800 mL of RO water. Add 167 mL of conc. H_2SO_4 to the mixture and bring to 1L with RO water.

Ferrion indicator-dissolve 1.485 g of 1,10-phenanthroline monohydrate and 695 g $FeSO_4.7H_2O$ in 50 mL of RO water and bring to 100 mL with RO water.

Sample Preparation:

1. Place 10 mL of sample/standard/blank in a 50 mL screw cap culture tube.
2. Add 14 mL of sulfuric acid reagent and 6 mL of 0.0417 M $K_2Cr_2O_7$ solution.
3. Mix the above solution well .
4. Heat sample/blank/standard in an oven at 150 °C for 2 hr.
5. Cool the tube to room temperature and read the intensity of the colour at 600 nm using the Bausch & Lomb Spectromic 70.
6. Chemical Oxygen Demand (COD) as mg O_2/L can be calculated base on the standard curve generated

reference : Personal communication with CCIW.

MISA TEST LIST FOR THIS METHOD CODE : reporting units mg/L

MOE TEST CODE	SMALLEST REPORTING INCREMENT	METHOD DETECTION LIMIT	* Water	HIGH CALI'B. STANDARD
COD	3	9.31	RO Water	500

* water used to determine MDL: reversed-Osmosis Deionized Water produced by Zenon

ANALYSIS OF METALS IN LIQUID AND SOLID SAMPLES BY INDUCTIVELY COUPLED PLASMA SPECTROSCOPY

1. Principle of the Method:

An inductively coupled plasma (ICP) source consists of a quartz tube, or "torch", through which a flow of argon gas is passed. The torch is surrounded by a water-cooled coil through which a radiofrequency electric field (27 MHz) is passed. The gaseous plasma is sustained by continuing ionization of argon by inductive coupling of the ionized gas with the high-frequency field. A sample aerosol is generated through use of an appropriate nebulizer and spray chamber and is carried into the plasma through an injector tube located within the torch. The sample aerosol is injected directly into the ICP, subjecting the constituent atoms to temperatures of about 6000°C. This results in almost complete dissociation of molecules. The high temperature of the plasma efficiently produces excited atomic (& ionic) levels which return to the ground state emitting energy thus producing emission spectra. The emitted light is focussed on a diffraction of rating which diffracts the light around a focal curve. Phototubes set at appropriate positions measure the light intensity at a specific wavelength for each element.

2. Sample Requirements

A minimum volume of 250 mL of liquid samples submitted in polyethylene terephthalate bottles is required. Samples must be preserved with nitric acid to pH<2.

3. Preparation of Liquid Samples:

1. Digest 25 mL of sample by evaporating to apporximately 15 mL in a microwave at approximately 300W after adding 2.5 mL of conc. HNO_3.

2. Cool and adjust final volume to 25 mL with RO water. Filter if necessary with a 0.45µ filter paper prior to analysis.

4. Preparation of Solid Samples:

1. Accurately weigh 0.5 g of solid sample that has been dried and ground to pass through a 100 mesh into an Erlenmeyer flask.

2. Add 5 mL of concentrated HCl plus 2 mL concentrated HNO_3. Filter if necessary with a 0.45µ filter paper or let stand overnight prior to analysis.

3. Digest for 30 minutes on a hot plate. Adjust volume to 50 mL with RO water.

If Hg analysis is required:

1. Accurately weigh 0.5 g of solid sample that has been dried and ground to pass through a 100 mesh into a Teflon microwave digestion vessel.

2. Add 7 mL aqua regia (5 mL HCl + 2 mL HNO_3).

3. Digest for 18 minutes in microwave oven (6 minutes at 100%, 6 minutes at 50%, 6 minutes at 100% power). Adjust volume to 50 mL with RO water.

If solids contain excessive organics, H_2O_2 is added, during the digestion procedures.

5. Reagent and Standard Preparation:

Stock Standards: 1000 mg/L standards are purchased depending on availability. Some standards are prepared from chemical solids as necessary.

Working Standards:

Standard 1: Blank

Standard 2: Ca, Mg, Ba, Cd, Co, Cu, Pb, Mn, Sr, Zn at 10 mg/L, K at 100 mg/L

Standard 3: Na, Al, Fe, Mo, Ni, Tl, Ti, Zr at 10 mg/L

Standard 4: B, Cr, P, Si, S at 10 mg/L

Standard 5: V, Y at 10 mg/L

Standard 6: Ag at 10 mg/L

Standard 7: Mg (383), Fe (271) at 100 mg/L

6. Analytical Procedure:

Samples are analyzed by the Inductively Coupled Plasma Atomic Emission Spectroscopy method as follows:

Determine the concentrations of the metals in the samples using a Thermo Jarrell Ash Model 61 ICAP spectrometer.

1. Turn on water flow and argon gas.

2. Start plasma. Allow to warm up for 1 to 2 hours.

3. Aspirate RO water then 2% HNO_3.

The emission lines used for the most frequent measured elements are listed below;

Ca - 315.8 nm
Mg - 279.5 nm
Mg - 383.2 nm
Na - 588.9 nm
K - 766.4 nm
Al - 308.2 nm
Ba - 493.4 nm
Be - 313.0 nm
B - 249.6 nm
Cd - 228.8 nm
Cr - 267.7 nm
Co - 228.6 nm
Cu - 324.7 nm

Pb - 220.3 nm
Mn - 257.6 nm
Mo - 202.0 nm
Ni - 231.6 nm
P - 178.2 nm
Si - 251.6 nm
Ag - 328.1 nm
Sr - 421.5 nm
S - 180.7 nm
Tl - 190.8 nm
Ti - 334.9 nm
V - 292.4 nm
Zn - 213.9 nm

Fe - 259.9 nm
Fe - 271.4 nm
Zr - 339.1 nm
Y - 371.0 nm

The instrumental conditions are:

Forward Power	1.14 kW
Reflected Watts	<10 KW
Argon Gas Flow- Torch	19 L/min
Auxiliary	0.9 L/min
Sample	0.66 L/min
Sample Flow Rate	1.7 mL/min
Vacuum	4 microns of Hg
Profile Reading on Micrometer	1305 to 1315
Nebulizer	fixed crossflow

Instrument Calibration: To be performed daily. Instrument calibration consists of a blank plus one standard at 10 ppm. The acid concentration must match that of prepared samples if samples contain greater than 5% acid, otherwise 1% nitric acid is used. Standard response values for the standard are plotted on control charts for Fe, Ca, Cu, Na and P and the standard response values are tabulated for all elements.

7. Quality Control

Calibration Verification: Calibration verification is performed at the beginning and end and every 12 samples during an analytical run. A reference standard at 10 ppm is used and the values must lie within ±10% of the theoretical.
IF ANY VALUES LIE OUTSIDE THE LIMITS THE INSTRUMENT IS RECALIBRATED AND THE PRECEDING 12 SAMPLES REANALYZED.

Method Blank: Analyze one for every 14 sample batch. The method blank is carried through the entire preparation and analysis to monitor for carryover from high samples.
IF THE BLANK FOR ANY ELEMENT IS APPROXIMATELY >5x MDL, THE AFFECTED SAMPLES MUST BE REDIGESTED AND REANALYSED.
The sample concentration is not to be corrected for the blank value.

Duplicate Sample Analysis: To be performed 1 in every 14 samples for MISA water samples and all soil samples. The control limit for RPD (relative percent difference) is 20%, if BOTH values >5x MDL and ±MDL otherwise. The duplicate values are entered into LIMS and results are tabulated.
EXCEEDENCES are flagged. REPEATS ARE REQUIRED if sample permits.

Interelement Corrections: Interelement correction factors have been determined for all 27 elements at concentrations spanning the linear dynamic range. The instrument software is programmed to compensate for these interferences. If concentrations are observed outside the linear dynamic range for elements which experience interference problems, a dilution is performed.

8. Calculations and Reporting

Element	Detection Limit	Detection Limit

	in Waters (mg/L)	in Soils (mg/Kg)
Calcium	0.02	20
Magnesium	0.05	40
Sodium	0.1	50
Potassium	0.5	100
Aluminum	0.03	30
Barium	0.001	0.2
Beryllium	0.001	0.1
Boron	0.01	10
Cadmium	0.002	0.2
Chromium	0.004	5
Cobalt	0.01	5
Copper	0.006	5
Iron	0.01	5
Lead	0.02	10
Manganese	0.005	5
Molybdenum	0.02	5
Nickel	0.01	5
Phosphorus	0.06	50
Silicon	0.05	10
Silver	0.01	5
Strontium	0.001	0.1
Sulphur	0.06	10
Thallium	0.06	20
Titanium	0.01	20
Vanadium	0.005	10
Zinc	0.005	5
Zirconium	0.01	5

Reference : Standard Methods for the Examination of Water and Wastewater, 16th edition, pp 180-182,1985

ANALYSIS OF LIQUID SAMPLES FOR TOTAL ORGANIC CARBON AND DISSOLVED ORGANIC CARBON

1. Principle of the Method:

Inorganic carbon which is present in samples as carbonate is first removed from the samples by sparging with a stream of nitrogen gas. This process is completed by transforming the aspirated sample into a thin turbulent stream of air to remove the remaining CO_2. The sample is then mixed with acid/persulphate and subjected to UV radiation in order to digest the organic compounds and convert them to CO_2. Dialysis of the resultant CO_2 through a gas-permeable silicone membrane to combine with a phenolphthalein solution causes a decrease on colour of the phenolphthalein solution proportional to the original organic carbon concentration. This colour change is measured at a specific wavelength.

2. Sample Requirements:

A minimum of 250 mL of sample is should be submitted in a glass or plastic bottle. All samples are store at 4° C. Provincial MISA regulations stipulate that water samples be analyzed within 10 days. Samples must be preserved with H_2SO_4, to a pH <2 but not <1.5

3. Sample Preparation:

1. Transfer 35 mL of preserved sample to a falcon tube.

2. Sparge for 30 minutes under a stream of 16 psi nitrogen gas to remove the inorganic carbon.

3. Sample is ready for analysis for DOC.

4. If the total suspended solids in the sample are greater that 15 ppm, TOC should be analyzed for separately.

5. For TOC analysis, homogenize the sample for 30 seconds using the Polytron at setting #10 before analysis.

4. Reagent and Standard Preparation:

Potassium Persulphate (1%): Prepared fresh each day. Dissolve 10.0 g of potassium persulphate in 800 mL RO water. Dilute to 1 L.

Sparge Acid (10N H_2SO_4): Prepare as required. Add 280 mL concentrated sulphuric acid to 600 mL RO water. Dilute to 1 L.

TRITON X-100 (1:1 Methanol): Combine 50 mL of methanol and 50 mL Triton X-100 and mix thoroughly.

RO Water with Surfactant: Dilute 1.0 mL of the Triton X-100 solution to 1 L with RO water and mix thoroughly.

Acid/Surfactant Solution: Prepare as required. Add 83 mL concentrated sulphuric acid to 800 mL RO water. When cool add 10 mL of the Triton X-100 solution. Dilute to 1 L.

K_2HPO_4 (0.025M) Solution: Dissolve 4.4 g of potassium phosphate in 800 mL of RO water. Dilute to 1 L with RO water and mix thoroughly.

Stock Buffer Solution: Dissolve 0.8 g of sodium carbonate monohydrate and 1.0 g sodium bicarbonate in RO water. Dilute to 100 mL. Store in tightly sealed glass bottle.

Phenolphthalein (1%) Solution: Dissolve 1.0 g of phenolphthalein in about 60 mL of methanol. Dilute to 100 mL with methanol and store in tightly sealed glass bottle.

Colour Reagent: (prepared fresh each run to prevent uptake of CO_2)

Working Range mg/L	0.2 - 10 mg/L	0.4 - 20 mg/L	1.0 - 50 mg/L (MISA range)	2.0-100
Buffer Solution	1.5 mL	2.0 mL	4.0 mL	8.0 mL
Phenolphthalein Solution	5.0 mL	2.0 mL	1.0 mL	1.0 mL
50% Triton X-100 (1:1 in methanol)	0.5 mL	0.5 mL	0.5 mL	0.5 mL

Combine reagents for appropriate working range and dilute to 1 L with RO water.

Sulphuric Acid Solution (1.0N) (Prepared biweekly) Slowly add 28 mL of sulphuric acid to about 600 mL RO water. Dilute to 1L and mix thoroughly.

Stock Standard (500 ppm Carbon): Dissolve 1.063 g potassium hydrogen phthalate in 600 mL RO water. Add 1.0 mL concentrated H_2SO_4. Dilute to 1 L.

Working Standards: (For 1.0 to 50 mg/L range. Prepared once each week.)
10.0 ppm C: Dilute 2 mL of the 500 ppm stock standard to 100 mL with 0.2 mL of 50% H_2SO_4 and RO water.

20.0 ppm C: Dilute 4 mL of the 500 ppm stock standard to 100 mL with 0.2 mL of 50% H_2SO_4 and RO water.

30.0 ppm C: Dilute 6 mL of the 500 ppm stock standard to 100 mL with 0.2 mL of 50% H_2SO_4 and RO water.

40.0 ppm C: Dilute 8 mL of the 500 ppm stock standard to 100 mL with 0.2 mL of 50% H_2SO_4 and RO water.

50.0 ppm C: Dilute 10 mL of the 500 ppm stock standard to 100 mL with 0.2 mL of 50% H_2SO_4 and RO water.

Control Standards:
Control A (40.0 ppm C): Dilute 8 mL of the 500 ppm stock standard to 100 mL with 0.2 mL of 50% H_2SO_4 and RO water.

Control B (10.0 ppm C): Dilute 2 mL of the 500 ppm stock standard to 100 mL with 0.2 mL of 50% H_2SO_4 and RO water.

5. Analytical Procedure:

Samples are analyzed by the Automated Colorimetry - Membrane Dialysis Method using the TRAACS 800 autoanalysis system as follows:

Daily start-up procedure for TRAACS 800:

1. Ensure an adequate supply of all reagents. Clean the flowcell daily.

2. Place all reagent lines in their respective containers.

3. With the UV lamp on, switch the proportioning pump on for 5 min. Run the RO H2O through the system for 1/2 hour.

4. Gently, but firmly , lock the platens. Switch on the soft ware, monitor, etc. Leave the intrument on for 30 min. to reach equilibrium.

The flow rates are set as follows:

- RO H2O	635 µL/min (GRN/GRN)
- 10N H_2SO_4	50 µL/min (ORN/GRN)
- Sample	484 µL/min (YEL/BLU)
- Colour Reagent	430 µL/min (YEL/YEL)
- Surfactant	50 µL/min (ORN/GRN)
- Persulphate	258 µL/min (WHT/WHT)
- K_2HPO_4	258µL/min (WHT/WHT)

Reagent absorbance should be around 0.40 AU with a top scale sensitivity at around 0.35 AU.

Instrument Calibration: After the instrument is set up, a six point calibration is run (Blank, 10, 20, 30, 40, 50 mg/L). A calibration curve is developed using a quadratic equation. If the higher standards are too low, this is an indication that the phosphate buffer is degrading..

Run format: Standards and samples are analyzed according to the following sequence:
P (primer-100% full scale standard), 1 S (RO H2O), 6 C(1 blank,5 calibrants), nS(control A- 80% of full scale, control B-20% of full scale), 1 Blank, Samples, H (100% of full scale), 2 blanks, G(gain=high std.), E(end of run)

The sequence of standards run at the end check and correct for drifting baseline throughout the run assuming constant drift. Instrument sensitivity is also determined by checking for carryover from high to low standards and applying a factor to all sample concentrations.

Reagent Absorbence Check: Performed when reagents or system is changed.
1. Place colour reagent line in RO water with surfactant and all other lines into reagents.
2. Turn on UV lamp and proportioning pump and allow to equilibrate for 10 minutes.

3. Set gain to 28 and baseline to about 2.5% of full scale.
4. Place colour reagent line into colour reagent and allow to equilibrate for 10 minutes.
5. Change in water baseline to colour reagent baseline should be 0.65 to 0.75 AU. Adjust amount of phenolphthalien in colour reagent until these limits are met.

Daily shut-down procedure:

1. Place sparging acid, persulphate and K_2HPO_4 lines in RO water without surfactant and allow the sampler line to pump for several min..

2. Place all other reagent lines in RO water with surfactant and allow the sampler line to pump for several min.

3. Allow the system to pump dry. Stop the pump and release the platens.

6. Quality Control:

Method Blank Analysis: Analyzed every 14 samples. Result must be less than the MDL.

Control Standard Analysis: Analyze after the calibration standards. Results must be within 10% of the expected values. Plot results of A+B and A-B on control charts.

Matrix Spike: (analyse on a frequency of 1 in 14)
Spike with 200 µL of 500 mg/L carbon solution into 10 mL of samples to give an added concentration of 10 mg/L. Calculate matrix spike % recovery as follows:

$$\text{Matrix Spike \% Recovery} = \frac{\text{spiked sample result - sample result}}{\text{spike added}} \times 100$$

% recovery limits: 75-125%

Check calculations and **re-analyze** if recoveries are outside the limts. Results are tabulated.

Method Blank Spike: (analyse on a frequency of 1 in 14)
Control standard B is used as the blank spike. Calculate blank spike % recovery as follows:

$$\text{Blank Spike \% Recovery} = \frac{\text{spiked blank result}}{\text{spike added}} \times 100$$

% recovery limits: 75-125%

Check calculations and **re-analyze** if recoveries are outside the limts. Results are tabulated.

Duplicates: Analyze on a frequency of 1 in 14 or 1 per each sample batch Calculate relative % difference (%RPD):

$$\%RPD = \frac{\text{first sample result-duplicate sample result}}{(\text{first sample result+duplicate sample result})/2} \times 100$$

% RPD limit: 20%

Check calculations and **re-analyze** if %RPD is greater than 20%.
Results are tabulated.

Reference: TRAACS 800 Industrial Method No. 860-87T

Standard Methods for the Examination of Water and Wastewater, 16th edition, 1985, method 417 C

ANALYSIS OF VOLATILE ORGANIC COMPOUNDS IN LIQUID AND SOLID SAMPLES BY GC/MS (EPA METHOD 624)

1. Principle of the method:

An inert gas is bubbled through a 5 mL water sample contained in a specially-designed purging chamber at ambient temperature . The purgeables are efficiently transferred from the aqueous phase to the vapour phase. The vapour is swept through a sorbent trap where the purgeables are trapped. After purging is completed, the trap is heated and volatiles are transferred to a second narrow-bore trap. The second trap is heated and backflushed with the inert gas to desorb the purgeables onto a gas chromatographic column. The gas chromatograph is temperature programmed to separate the purgeables which are then detected with a mass spectrometer.

2. Sample Requirements:

Water samples should be received in a 40 mL amber glass vials with a teflon lined septum cap. Sample bottles should be filled to overflowing so that when capped, no headspace is trapped. For MISA industrial effluent samples, 3 grabs are taken of 2x40 mL for a total of 6 vials to constitute one sample. A minimum of 30g of solid sample should be submitted in the same type of vial. The samples are stored at 4° C. Provincial MISA regulations stipulate that water samples be analyzed within 7 days.

3. Preparation of Liquid Samples:

Composite one third of the volume of each of the three grab samples into a clean 40 mL vial prior to analysis. No other advance preparation is necessary.

4. Preparation of Solid Samples:

Headspace Method: Accurately weigh 10 g of solid sample into a 40 mL vial. Put in a water bath at 70°C for 30 minutes. Withdraw 1 mL of headspace and inject into the injection port of the instrument bypassing the purging apparatus.

Purge and Trap Method: Accurately weigh 10 g of solid sample into a 40 mL vial. Fill with RO water and mix to form a slurry. Put 3 mL of slurry into a purging vessel attached to the instrument and maintain at 40°C using a water bath during purging.

5. Reagent and Standard Preparation:

Stock Standards: Concentrated standards at 2 µg/µL of each compound are purchased. Acrolein and acrolynitrile are prepared in methanol from neat compounds.

Working Standards: 10 µL of each of the stock standards are combined and made up to 400 µL with methanol.

Calibration Standards:
10 µg/L Standard: Spike 8 µL of working standard into a 43 mL vial (assumed to be 40

mL) filled to overflowing with RO water.
20 µg/L Standard: Spike 16 µL of working standard into a 43 mL vial (assumed to be 40 mL) filled to overflowing with RO water.
40 µg/L Standard: Spike 32 µL of working standard into a 43 mL vial (assumed to be 40 mL) filled to overflowing with RO water.
Prepare standards and put in an ultrasonic bath for 20 minutes. Allow to equilibrate at room temperature.

6. Analytical Procedure:

Samples are analyzed using a Purge and Trap - GC/MSD with a capillary column according to the following procedure:

Instrument Set-up:

The instrumental conditions for volatiles anaysis are summarized below:
Sparge: Helium 30 mL/min for 11 min.
Temperature :
Trap #1 (wide bore) - Cool: 45°C Heat: 250°C
Trap #2 (narrow bore) Cool: 45°C Heat: 250°C
Transfer Line 250°C
GC Carrier Flow 2 mL/min

The Gas Chromatographic conditions for the two HP-MSDs are listed below:

MSD3	MSD4
Column: 30M DB5 0.25 mm ID	Column: 30M DB624 0.32 mm ID
Temperature program:	Temperature program:
- 20°C for 2 min	0°C for 3 min
- 20°C to 52°C at 8°C/min	0°C to 52°C at 8°C/min
52°C to 120°C at 12°C/min	52°C to 120°C at 10°C/min
120°C to 280°C at 25°C/min	120°C to 200°C at 20°C/min
Injector: On-column	Injector: On-column

The mass spectrometer conditions used in the analysis are:
Electron Impact mode, scanning 40-350 AMU each second
Electron energy 70eV
Em voltage 1300eV (or as required)
Emission Current 0.5 A

Instrument Tuning:

1. Inject 100 ng of BFB (bromomfluorobenzene) into every sample.

2. Check the abundance criteria of the BFB in the mid-range standard at the beginning and as part of each calibration.

m/z	Ion Abundance Criteria
50	15 - 40% of base peak
75	30 - 60% of base peak
95	base peak
96	5 - 9% of base peak
173	<2% of mass 174
174	>50% of base peak
175	5 - 9% of mass 174
176	>95% & <101% of mass 174
177	5 - 9% of mass 176

3. Print out the mass spectrum of the tuning check associated with each calibration and file with the sample data.

4. The tune must meet abundance criteria before proceeding to samples

Initial Calibration: A three point calibration (10, 20, 40 ug/L or 50, 100, 200 total ng) is performed if the Relative Response Factor from an Continuing (one point) Calibration standard differs by greater than 20 to 25% from the average of the RRFs of the last initial calibration.

1. Calculate the %RSD (Relative Standard Deviation) for the list of target compounds. They must be less than ±30%

2. Calculate the Relative Response Factors (RRF) for the list of target compounds. They must all be > 0.30

$$\text{RRF} = \frac{\text{area of the compound to be measured}}{\text{area of the internal std. for the compound}} \times \frac{\text{conc. of the internal std.}}{\text{conc. of the compound to be measured}}$$

3. Repeat the injection if any criteria is not met. The printout from the data system is filed with the raw data.

4. Plot the RRF of the the internal standards at 20 µg/L on a control chart at every calibration. Initial and continuing calibrations are represented on the same chart.

Continuing Calibration: A single point calibration at 20 µg/L is performed if the condition described above is met. It must be performed at least every 12 hours if the 20 µg/L standard has drifted more than 20%.

1. Calculate the RRF for the list of target compounds. They must all be > 0.30

2. Calculate % difference of RRF of the list of target compounds between single & multi-point (mean value) calibration. They must be <20 to 25%. If >25% repeat injection. If fails again do full calibration.

$$\%\ \text{Difference} = \frac{\text{average RRF from initial calibration} - \text{RRF from current calibration}}{\text{average RRF from initial calibration}} \times 100$$

3. The printout from the data system is filed with the raw data.

4. Plot the RRF of the the internal standards at 20 µg/L on a control chart at every calibration. Initial and continuing calibrations are represented on the same chart.

Sample Analysis:

1. Analyze a distilled water blank along with each batch of samples.

2. Load a series of 43 mL vials containing standard/blank/sample onto the auto-sampler tray.

3. Standard/blank/sample is automatically spiked with 3 surrogate standards, 3 internal standards (100 ng each) and 10 µL of injection standard 1,4-dichlorobutane (40 ng/µl) prior to analysis.

4. Standard/blank/sample is analyzed using an Envirochem Series 810 volatile analyzer connected to the HP-MSD GC/MS system.

Run Format: Standards are run first followed by two blanks, then samples. Duplicates are run side by side.

Dilutions: If sample concentrations are known to be or anticipated to be higher than the normal operating range, dilutions are performed by compositing the sample first and withdrawing a known amount from a clean blank sample. The blank is then filled to overflowing with the high concentration sample and capped immediately.

7. Quality Control:

Method Blank Analysis Analysed 1 per 12 hours or 1 per sample batch. Blanks should not contain >MDL of any compound, except methylene chloride, toluene, 2-butanone and acetone are acceptable up to 5 x MDL. Results are tabulated and control charts of absolute area counts are plotted for methylene chloride, toluene, benzene, chloroform and acetone. All sample data are reported uncorrected for blanks and also corrected depending on project requirements.

Internal Standards: The internal standards (IS) are 1,4-Difluorobenzene, d5-Chlorobenzene and d4-1,2-dichloroethane. Every sample, standard, method blank and matrix spike sample are spiked with 200 ng of each IS before injection.
Check retention time (RT) of each compound; must be within ±30 seconds between runs. If >30 seconds the system has to be inspected for malfunction and correction made as required.

Surrogate standards: Surrogate volatiles are d8-toluene, BFB and d4-1,2-dichloroethane. Every sample, standard, method blank and matrix spike sample are spiked with 200 ng of each compound. NO DEVIATION OF CONCENTRATION IS ALLOWED

Calculate the recovery of each surrogate:

$$\% \text{ Surrogate Recovery} = \frac{\text{quantity determined by analysis}}{\text{quantity added to sample}} \times 100\%$$

compound	water % recovery	soil % recovery
d8-toluene	88-110	81-117
BFB	86-115	74-121
d4-DCE	76-114	70-121

Check calculations and reanalyse if recoveries are outside these limits. Surrogate recoveries are reported with sample results.

Matrix spike: Analyse on a frequency of 1 in 20 or 1 per sample batch matrix spike duplicates. Spike with 16 µL of the working standard (200 ng of each compound).

Calculate matrix spike % recoveries for each compound

$$\text{matrix spike \% recovery} = \frac{\text{spike sample result} - \text{sample result}}{\text{spike added from spiking mix}} \times 100$$

Duplicates: For duplicate analyses, calculate Relative % Difference (RPD)

$$\text{RPD} = \frac{\text{first sample value} - \text{duplicate sample value}}{(\text{first sample value} + \text{duplicate sample value})/2} \times 100$$

Expected % recoveries and RPD are:

	water		soil	
Compound	% recovery			
chlorobenzene	75-130	13	60-133	21
toluene	76-125	13	59-139	21
benzene	76-127	11	66-142	21
1,1-dichloroethene	61-145	14	59-172	22
trichloroethene	71-120	14	62-137	24

Data outside these limits DO NOT require reanalysis, but should be noted as part of a QA report.

8. Calculations and Reporting:

See attached list of target compounds, method detection limits and smallest reporting increments.

Reference : EPA Method 624 - Purge & Trap

ANALYSIS OF SEMI-VOLATILE ORGANIC COMPOUNDS BY GC/MS (EPA METHOD 625)

1. Principle of the Method:

A measured volume of sample, approximately 1 L, is extracted with methylene chloride at a pH greater than 11 using a separatory funnel. The pH is adjusted to less than 2 and the sample is extracted again with methylene chloride. The methylene chloride extract is dried, concentrated to a volume of 1mL and analyzed by GC/MS. Qualitative identification of the parameters in the extract is performed using the retention time and the relative abundance of three characteristic masses (m/z) for each compound. Quantitative analysis is performed using either external or internal standard techniques with a single characteristic mass.

2. Sample Requirements:

Water samples should be received in 1L brown glass bottles (2 per sample). A minimum of 30 g of solid sample should be submitted. The samples are stored at 4°C. Provincial MISA regulations stiplulate that water samples be analyzed within 30 days.

3. Preparation of Liquid Samples:

Approximately 1 L of water sample /blank is prepared according to the following procedure:

1. Transfer sample/blank into a 2 L separatory funnel which has been rinsed with acetone and methylene chloride.

2. Rinse the sample bottle with methylene chloride (10-20 mL) and transfer the rinsing to the separatory funnel.

3. Adjust the pH of the aqueous phase to 12 with saturated KOH, then spike with 20 uL of the surrogate standard mix which contains 1 µg/µL each of d5-nitrobenzene, 2-fluorobiphenyl, 2,4,6-tribromophenol, d14-p-terphenyl and d14-p-terphenyl prior to extraction.

4. Add 80 mL methylene chloride to the separatory funnel and shake vigorously for 2 min.

5. Drain the methylene chloride layer through a 1.5 inch anhydrous Na_2SO_4 column in an Allihn filter.

6. Extract the aqueous layer twice as above with additional 70 mL aliquots of methylene chloride.

7. Adjust the pH to less than 2 using HCl. Repeat steps 4 to 6.

8. Rinse the column with additional 20 mL of methylene chloride. Drain the remaining methylene chloride from the column by vaccum.

9. Evaporate the combined extract to approximately 2 mL by rotary evaporation.

10. Transfer the extract to a calibrated centrifuge tube and evaporate to less than 1 mL under a gentle stream of N_2.

11. Spike 20 µl of the internal standard mix (1 µg/µl) to the extract and adjust the final volume to 1 ml with methylene chloride prior to GC/MS analysis.

12. Measure the sample volume (aqueous phase) in a 1 L graduated cylinder and record the measurement.

4. Preparation of Solid Samples:

1. Accurately weigh approximately 1 to 10 g wet weight of sample depending on the nature of the sample. A subsample is taken for dry weight determination.

2. Add sodium sulphate to the sample and mix until granular, then place into a Soxhlet thimble.

3. Spike the sample with 20 µL of the surrogate standard mix which contains 1 µg/µL each of d5-nitrobenzene, 2-fluorobiphenyl, 2,4,6-tribromophenol, d14-p-terphenyl and d14-p-terphenyl prior to extraction.

4. Add 300 to 400 mL methylene chloride to the sample and Soxhlet overnight.

5. Evaporate the extract to approximately 1 mL by rotary evaporation.

6. Transfer the extract to a calibrated centrifuge tube and evaporate to less than 1 mL under a gentle stream of N_2.

7. Spike 20 µl of the internal standard mix (1 µg/µl) to the extract and adjust the final volume to 1 ml with methylene chloride prior to GC/MS analysis.

8. Results are normally reported on a dry weight basis.

5. Reagent and Standard Preparation:

Stock Standards: Concentrated standards at 2000 ng/µL of each compound are purchased.

Calibration Standards:
10 mg/L Standard: Spike 125 µL of working standard into a 25 mL volumetric flask.filled with methylene chloride. Make up to volume.
25 mg/L Standard: Spike 312.5 µL of working standard into a 25 mL volumetric flask.filled with methylene chloride. Make up to volume.
40 mg/L Standard: Spike 500 µL of working standard into a 25 mL volumetric flask.filled with methylene chloride. Make up to volume.
Prepare standards and put in an ultrasonic bath for 5 to 10 minutes. Store in refrigerator.

6. Analytical Procedure:

Samples are analyzed using a HP GC/MSD according to the following procedure:

Instrument Set-up:

The Gas Chromatographic conditions of the HPMSD GC/MS system used for the analysis are listed below:
Column: 30M DB5-625 0.25 mm ID
Column Flow: He at 20 cm/sec.
GC/MS Interface: Direct
Injector Mode: Splitless
Temperature program:
50°C for 5 min

50°C to 220°C at 12°C/min
220°C to 300°C at 16°C/min, hold for 20 min
Transfer Area: 280°C

The mass spectrometer conditions used in the analysis are:
Electron Impact mode
Electron Multiplier 2400V or as required
Scan 45 - 550 a.m.u

Instrument Tuning: At the beginning of each batch of samples the instrument performs an Autotune function in which the combination of electron multiplier voltage, ion focus voltage and the abundance of ion 502 are scrutinized. A report is printed out.

Initial Calibration: A three point calibration (10, 25, 40 mg/L) is performed if the Relative Response Factor from an Continuing (one point) Calibration standard differs by greater than 20 to 25% from the average of the RRFs of the last initial calibration.

1. Calculate the %RSD (Relative Standard Deviation) for the list of target compounds to check for system linearity. They must be less than ±30%

2. Calculate the Relative Response Factors (RRF) for the list of target compounds to check the condition of the system components. They must all be > 0.05.

$$\text{RRF} = \frac{\text{area of the compound to be measured}}{\text{area of the internal std. for the compound}} \times \frac{\text{conc. of the internal std.}}{\text{conc. of the compound to be measured}}$$

3. Repeat the injection if any criteria is not met. The printout from the data system is filed with the raw data.

4. Plot the RRF of the the internal standards at 25 µg/L on a control chart at every calibration. Initial and continuing calibrations are represented on the same chart.

Continuing Calibration: A single point calibration at 25 µg/L is performed if the condition described above is met. It must be performed at least every 12 hours if the 25 µg/L standard has drifted more than 20%.

1. Calculate the RRF for the list of target compounds. They must all be > 0.05 .

2. Calculate % difference of RRF of the list of target compounds between single & multi-point (mean value) calibration. They must be <20 to 25%. If >25% repeat injection. If fails again do full calibration.

$$\%\ \text{Difference} = \frac{\text{average RRF from initial calibration} - \text{RRF from current calibration}}{\text{average RRF from initial calibration}} \times 100$$

3. The printout from the data system is filed with the raw data.

4. Plot the RRF of the the internal standards at 20 µg/L on a control chart at every calibration. Initial and continuing calibrations are represented on the same chart.

Run Format: The analytical run format is standard(s)/spike/blank/samples.

7. Quality Control:

Method Blank Analysis Analysed 1 per sample batch. Blanks should not contain >MDL of any compound (except for some phthalates) . Results are tabulated. All sample data are reported corrected or uncorrected for blanks as required by the project.

Internal Standards: The internal standards (IS) are d4-1,3-dichlorobenzene, d10-acenaphthen d10-phenanthrene and d12-chrysene. 1 mL of every sample, standard, method blank and matrix spike sample extract are spiked with 20 µL if internal standard mix (in methylene chloride) which contains 1 µg/µL before injection. Check retention time (RT) of each compound; must be within ±30 seconds between runs. If >30 seconds the system has to be inspected for malfunction and correction made as required. Plot the absolute area counts of d10 phenanthrene and d12-chrysene

Surrogate standards: Surrogate semi-volatiles are 2,4,6-tribromophenol, d5-nitrobenzene, d1 terphenyl, 2-fluorobiphenyl and d5-phenol. Every sample, standard, method blank and matrix spike sample are spiked with 20 µg each of d5-nitrobenzene, d14- terphenyl, 2-fluorobiphenyl, 4 µg each of 2,4,6-tribromophenol and d5-phenol. NO DEVIATION OF CONCENTRATION IS ALLOWED

Calculate the recovery of each surrogate:

$$\%\ \text{Surrogate Recovery} = \frac{\text{quantity determined by analysis}}{\text{quantity added to sample}} \times 100\%$$

Expected recoveries are:

2,4,6-tribromophenol	30 - 120%
d5-nitrobenzene	30 - 120%
d14- terphenyl	30 - 120%
2-fluorobiphenyl	30 - 120%
d5-phenol	10 - 95%

Check calculations and reanalyse if recoveries are outside these limits. Surrogate recoveries are reported with sample results.

Matrix spike: Analyse on a frequency of 1 in 20 or 1 per sample batch matrix spike duplicates. 1 L tap water is spiked with 1 mL of a mixture which contains all the target compounds. The concentration of the spike solution is equal to the mid opint of the three point calibration standard

Calculate matrix spike % recoveries for each compound

$$\text{matrix spike}\ \%\ \text{recovery} = \frac{\text{spike sample area count} - \text{sample area count}}{\text{area count in spiking mix}} \times 100$$

Expected recoveries are: 40 - 120%. Data outside the limits DO NOT require reanalysis

Duplicates: For duplicate analyses, calculate Relative % Difference (RPD)

$$\text{RPD} = \frac{\text{first sample value} - \text{duplicate sample value}}{(\text{first sample value} + \text{duplicate sample value})/2} \times 100$$

Expected RPD is <25. Data outside these limits require reanalysis, and unusual occurences shou be noted as part of a QA report.

8. Calculations and Reporting:

See attached list of target compounds, method detection limits and smallest reporting increments

Appendix B

Bench-Scale Testing Data

Table B-1 : Bench Scale Screening Test Data, Leachate Adjusted to pH 8 with NaOH

(1) Pure Water Flux Test

Time (min)	Temperature (°c)	Permeate Rate (ml/min)	Pressure (psig)	
			Inlet (PI)	Outlet (PO)
0	20	120	40	39
15	18	105	40	39
30	18	102	40	39

(2) Microfiltration Test

100 ml of a 13% NaOH solution added to 10 (US) gallons of raw leachate to pH 8 (290 mg/L NaOH)

Time (min)	Temperature (°c)	Permeate Rate (ml/min)	Pressure (psig)	
			Inlet (PI)	Outlet (PO)
0	26	105	40	39
15	27	100	40	39
30	28	97	40	39

(3) Permeate Quality

Concentrate TSS (mg/L)	Concentrate TDS (mg/L)	Permeate TDS (mg/L)	Permeate Total Iron (mg/L)	Permeate Ferric Iron (mg/L)
313	807	680	0.85	0.83

Table B-2 : Bench Scale Screening Test Data, Leachate Adjusted to pH 10 with Lime/Soda Ash

(1) Pure Water Flux Test

Time (min)	Temperature (°c)	Permeate Rate (ml/min)	Pressure (psig)	
			Inlet (PI)	Outlet (PO)
0	20	110	40	40
15	20	89	40	40
30	21	85	40	40

(2) Microfiltration Test

200 ml of a 15% lime slurry (660mg/L lime), and 200 ml of a 21.5% soda ash solution (950mg/L Na_2CO_3), were added to 10 (US) gallons of raw leachate to pH 10.

Time (min)	Temperature (°c)	Permeate Rate (ml/min)	Pressure (psig)	
			Inlet (PI)	Outlet (PO)
0	20	110	40	40
15	22	107	40	40
30	21	102	40	40

3) Permeate Quality

Concentrate TSS (mg/L)	Concentrate TDS (mg/L)	Permeate TDS (mg/L)	Permeate Total Iron (mg/L)	Permeate Ferric Iron (mg/L)
1103	867	740	0.58	0.58

Table B-3 : Bench Scale Microfiltration Test Results after Caustic Treatment to pH 8

Stability Test Data on Raw Leachate Treated with 290mg/L NaOH

Time (min)	Temperature (°c)	Operating Pressure (psig)	Concentrate Flow Rate (lpm)	Permeate Flow Rate (ml/min)	Flux Rate (USgfd)
0	20	39	16	192	288
30	17	39	16	134	201
45	16	39	16	118	177
60	18	39	16	120	180
90	19	38.5	16	118	177
120	18	38.5	16	110	165

Concentration Run on Leachate Treated with 290mg/L NaOH

Time (min)	Temperature (°c)	Operating Pressure (psig)	Concentrate Flow Rate (lpm)	Permeate Flow Rate (ml/min)	Permeate Removed (L)	Concentrate Volume (L)	Volume Reduction (%)	Flux Rate (USgfd)
120	18	38.5	16	110	0	50	0	165
141	18	38.5	16	94	2	48	4	141
164	18	38.5	16	87	4	46	8	130
188	18	38.5	16	85	6	44	12	127
216	18	38.5	16	80	8	42	16	120
-	-	-	-	-	10	40	20	-
330	18	38	16	70	14	36	28	105
360	-	-	-	-	16	34	32	-
391	18	38	16	64	18	32	36	96
425	-	-	-	-	20	30	40	-
459	18	38	16	60	22	28	44	90
495	-	-	-	-	24	26	48	-
515	18	38	16	60	25	25	50	90
* 515	19	38	16	64	25	40	38	96
554	-	-	-	53	27	38	42	79
595	18	38	16	48	29	36	45	72
641	-	-	-	39	31	34	48	58
692	18	38.5	16	42	33	32	51	63
745	-	-	-	39	35	30	54	58
802	18	38	16	38	37	28	57	57
863	-	-		35	39	26	60	52
933	20	38	16	38	41	24	63	57

* - 15 litres of feed added

Table B-4 : Bench Scale Microfiltration Test Results after Lime/Soda Ash Treatment to pH 10

Stability Test Data on Raw Leachate Treated with 660mg/L Lime and 950 mg/L Soda Ash

Time (min)	Temperature (°c)	Operating Pressure (psig)	Concentrate Flow Rate (lpm)	Permeate Flow Rate (ml/min)	Flux Rate (USgfd)
0	19	39	16	114	171
30	19	39	16	114	171
45	17	39	16	106	159
60	17	39	16	100	150
90	-	-	-	-	-
120	17	39	16	70	105
150	18	39	16	71	106

Concentrate Test Data on Raw Leachate Treated with 660mg/L Lime and 950 mg/L Soda Ash

Time (min)	Temperature (°c)	Operating Pressure (psig)	Concentrate Flow Rate (lpm)	Permeate Flow Rate (ml/min)	Permeate Removed (L)	Concentrate Volume (L)	Volume Reduction (%)	Flux Rate (USgfd)
150	18	39	16	71	0	60	0	106
241	18	39	16	92	6	54	10	138
266	18	-	-	-	8	52	13	-
288	18	-	-	-	10	50	17	-
312	18	39	16	86	12	48	20	129
338	18	39	16	84	14	46	23	126
362	18	39	16	86	16	44	27	129
387	18	39	16	86	18	42	30	129
412	18	39	16	82	20	40	33	123
447	18	39	16	80	23	37	38	120
472	17	39	16	96	25	35	42	144
492	17	39	16	94	27	33	45	141
526	18	39	16	91	29	31	48	136
543	18	39	16	95	30	30	50	142
* 557	-	-	-	-	30	50	38	-
580	17	39	16	90	32	48	40	135
602	17	39	16	89	34	46	43	133
626	17	39	16	87	36	44	45	130
649	17	39	16	87	38	42	48	130
675	17	39	16	84	40	40	50	126
735	17	39	16	79	42	38	53	118
853	17	39	16	79	46	34	58	118
915	17	39	16	78	50	30	63	117

* - 20 litres of feed added

Appendix C

Microfiltration System

Field Data

Figure C-1
Microfiltration System Operation - Pilot Test # 3

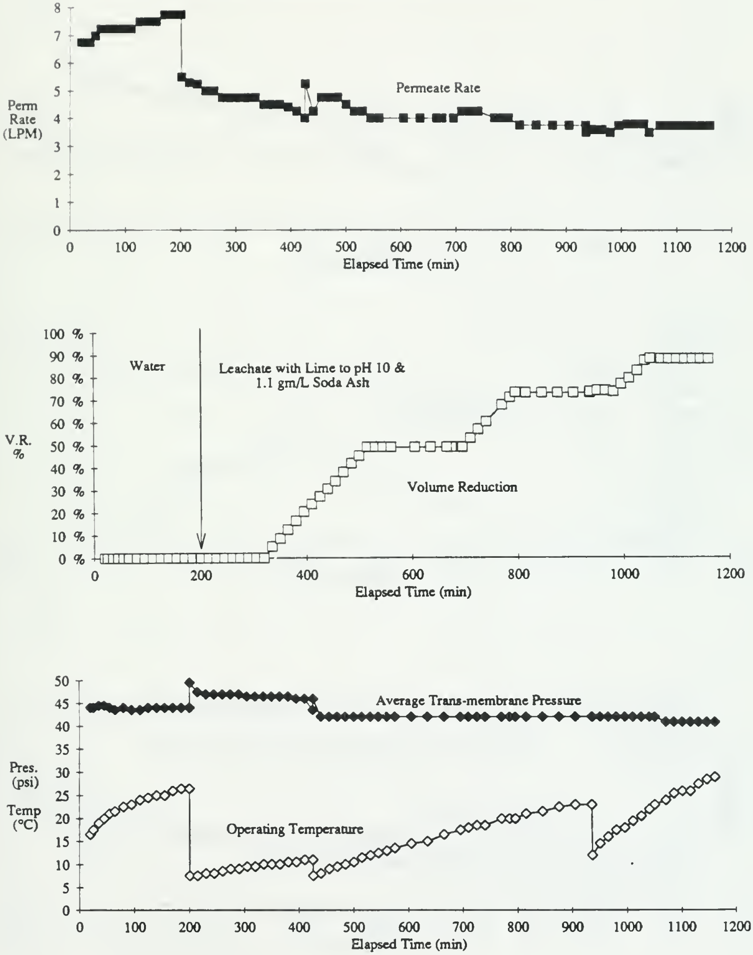

Figure C-2
Microfiltration System Operation - Pilot Run # 5

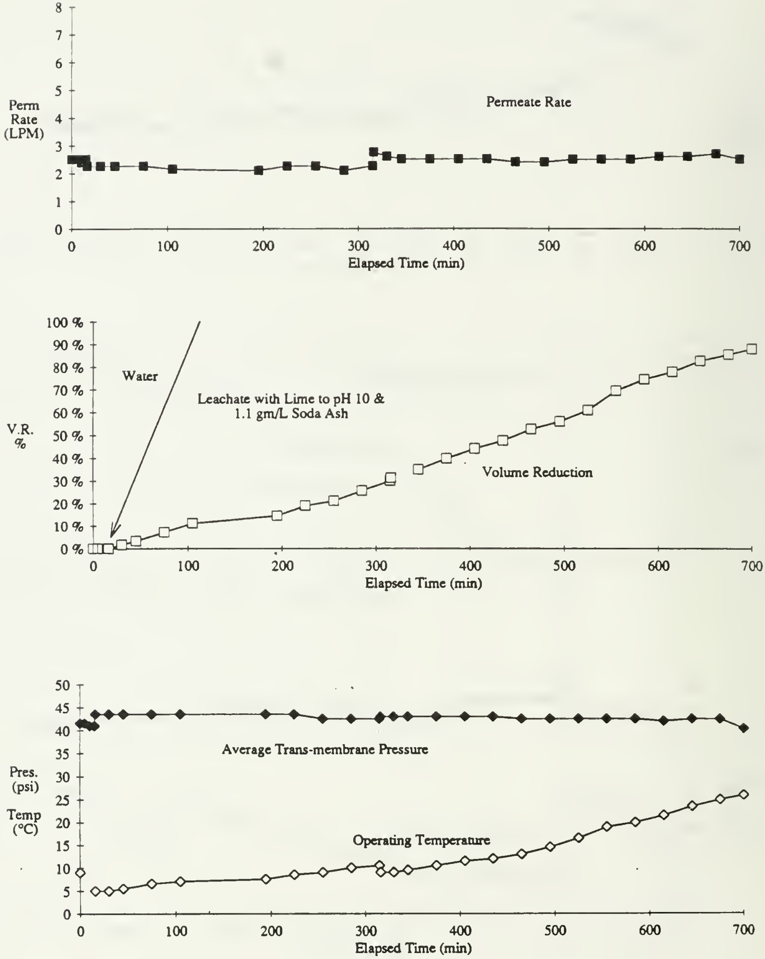

Figure C-3
Microfiltration System Operation - Pilot Test # 6/7

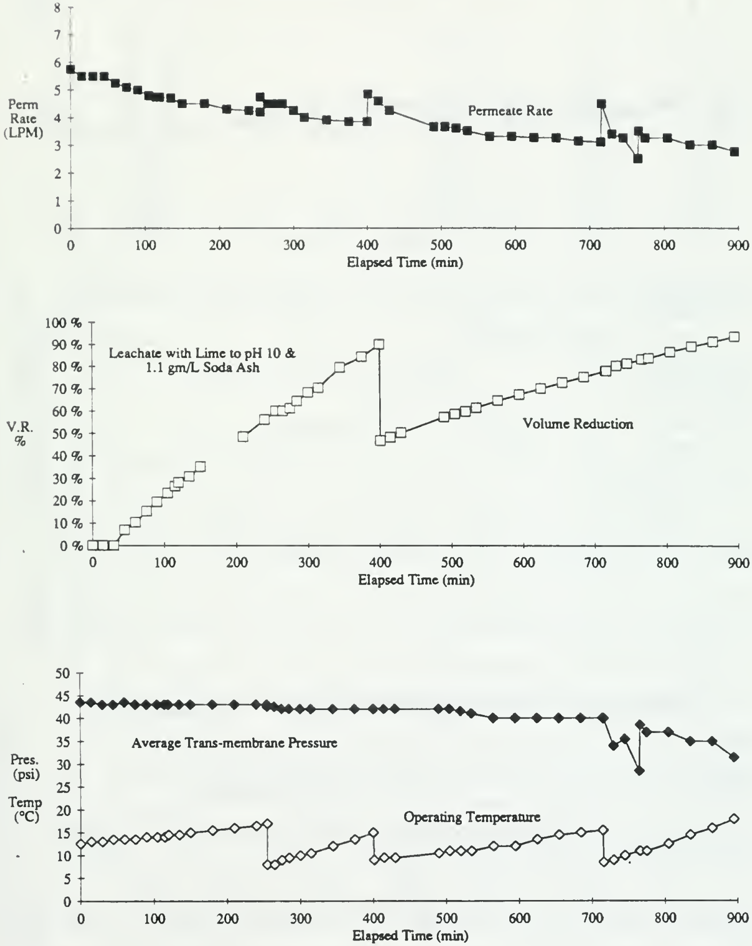

Figure C-4
Microfiltration System Operation - Pilot Test # 10

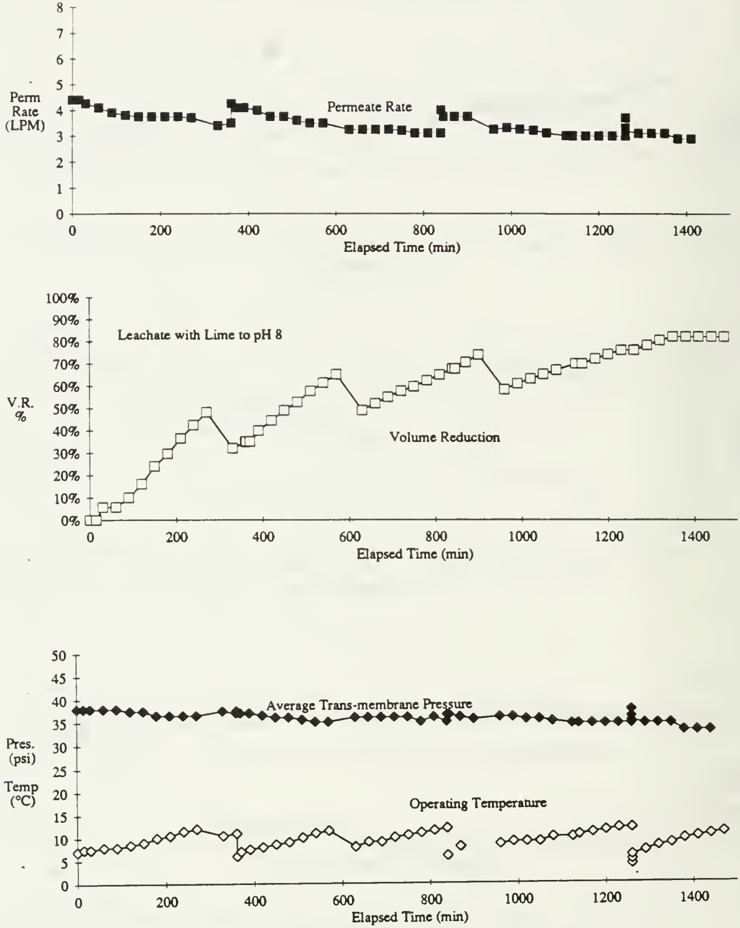

Table C-1 : Field Data Log Sheet

Application : Leachate Treatment
System : Microfiltration
Test No. 3

Type : Stability, 0%, 50%, 75%, 90%
Pretreatment : Lime/Soda Ash to pH 10

Date: Oct 3'89

Real Time	Elapsed Time (min)	Temp. (°C)	Membrane Pressure Pin (psig)	Pout (psig)	Pave (psig)	Permeate Rate (LPM)	Tank Level (L)	Volume Reduction (%)	Comments
1125	0	16.0	60	27	43.5	7.5	-	0%	Baseline tap water flux (test #1)
1130	5	16.5	60	27	43.5	7.25	-	0%	50 L tap water
1145	20	16.5	60	28	44	6.75	-	0%	40 L RO water added to keep temp. down
1150	25	17.5	60	28	44	6.75	-	0%	
1200	35	19.0	61	28	44.5	6.75	-	0%	
1210	45	20.0	61	28	44.5	7	-	0%	
1220	55	21.0	61	27	44	7.25	-	0%	
1230	65	21.5	60	27	43.5	7.25	-	0%	
1245	80	22.5	61	27	44	7.25	-	0%	
1300	95	23.0	60	27	43.5	7.25	-	0%	
1315	110	24.0	60	27	43.5	7.25	-	0%	
1330	125	24.5	61	27	44	7.5	-	0%	
1345	140	25.0	61	27	44	7.5	-	0%	
1400	155	25.0	61	27	44	7.5	-	0%	
1415	170	26.0	61	27	44	7.75	-	0%	
1430	185	26.5	61	27	44	7.75	-	0%	
1445	200	26.5	61	27	44	7.75	-	0%	
1145	201	7.5	69	30	49.5	5.5	1740	0%	No cooling necessary
1200	215	7.5	65	30	47.5	5.3	-	0%	Conc. flow ~ 40usgpm ~ 150lpm
1215	230	8.0	64	30	47	5.25	-	0%	
1230	245	8.0	64	30	47	5	-	0%	permeate 0.25 ppm Fe (hach)
1245	260	8.5	64	30	47	5	-	0%	Raw feed ~285 ppm Fe
1300	275	9.0	64	30	47	4.75	-	0%	
1315	290	9.0	64	30	47	4.75	-	0%	
1330	305	9.5	64	29	46.5	4.75	-	0%	
1345	320	9.5	64	29	46.5	4.75	-	0%	
1400	335	10.0	64	29	46.5	4.75	1650	5%	Start concentrating to 50 %
1415	350	10.0	64	29	46.5	4.5	1590	8%	
1430	365	10.0	64	29	46.5	4.5	1520	12%	
1445	380	10.5	64	29	46.5	4.5	1450	16%	
1500	395	10.5	64	28	46	4.4	1380	20%	
1515	410	11.0	64	28	46	4.25	1320	24%	
1530	425	11.0	62	25	43.5	4	1260	27%	Shut down @ 1530
930	426	7.5	64	28	46	5.25	1260	27%	Continue concentrating to 50 %
945	440	8.0	62	22	42	4.25	1200	30%	
1000	455	9.0	62	22	42	4.75	1140	34%	

Real Time	Elapsed Time (min)	Temp. (°C)	Membrane Pressure Pin (psig)	Membrane Pressure Pout (psig)	Membrane Pressure Pave (psig)	Permeate Rate (LPM)	Tank Level (L)	Volume Reduction (%)	Comments
1015	470	9.5	62	22	42	4.75	1070	38%	
1030	485	10.0	62	22	42	4.75	1000	42%	
1045	500	10.5	62	22	42	4.5	940	45%	
1100	515	11.5	62	22	42	4.25	870	49%	Start 50 % stability run
1115	530	12.0	62	22	42	4.25	-	49%	
1130	545	12.5	62	22	42	4	-	49%	Permeate ~0.11 ppm Fe
1145	560	13.0	62	22	42	4	-	49%	Concentrate~360 ppm Fe
1200	575	13.5	62	22	42	4	-	49%	
1230	605	14.5	62	22	42	4	-	49%	
1300	635	15.0	62	22	42	4	-	49%	
1330	665	16.5	62	22	42	4	-	49%	
1400	695	17.5	62	22	42	4	870	49%	
1415	710	18.0	62	22	42	4.25	800	53%	Start concentrating to 75 %
1430	725	18.5	62	22	42	4.25	730	57%	
1445	740	18.5	62	22	42	4.25	670	60%	
1515	770	20.0	62	22	42	4	540	68%	
1530	785	20.0	62	22	42	4	480	71%	
1540	795	20.0	62	22	42	4	440	73%	Start 75 % stability run
1600	815	21.0	62	22	42	3.75	-	73%	
1630	845	21.5	62	22	42	3.75	-	73%	Permeate ~0.11 ppm Fe
1700	875	22.5	62	22	42	3.75	-	73%	Concentrate~625 ppm Fe
1730	905	23.0	62	22	42	3.75	-	73%	
1800	935	23.0	62	22	42	3.75	-	73%	Shut down @ 1800
1015	936	12.0	62	22	42	3.5	435	74%	Repeat 75 % stability
1030	950	14.5	62	22	42	3.6	-	74%	
1045	965	16.0	62	22	42	3.6	-	74%	
1100	980	17.5	62	22	42	3.5	435	74%	
1115	995	18.0	62	22	42	3.75	375	77%	Start concentrating to 90 %
1130	1010	19.5	62	22	42	3.8	330	79%	high flow levels due to back pressure from
1145	1025	20.5	62	22	42	3.8	270	83%	permeate line valve ?
1200	1040	22.0	62	22	42	3.8	190	87%	
1210	1050	23.0	62	22	42	3.5	175	88%	Start 90 % stability run
1230	1070	24.0	60	22	41	3.75	-	88%	
1245	1085	25.5	60	22	41	3.75	-	88%	Permeate ~0.1 ppm Fe
1300	1100	26.0	60	22	41	3.75	-	88%	Concentrate~1580 ppm Fe
1315	1115	26.0	60	22	41	3.75	-	88%	
1330	1130	27.5	60	22	41	3.75	-	88%	
1345	1145	28.5	60	22	41	3.75	-	88%	
1400	1160	29.0	60	22	41	3.75	-	88%	Shut down @ 1400

Table C-2 : Field Data Log Sheet

Application : Leachate Treatment
System : Microfiltration
Test No. 5

Type : Concentration to 90% Recovery
Pretreatment : Lime/Soda Ash to pH 10

Date: Oct 10'89

Real Time	Elapsed Time (min)	Temp. (°C)	Membrane Pressure Pin (psig)	Pout (psig)	Pave (psig)	Permeate Rate (LPM)	Tank Level (L)	Volume Reduction (%)	Comments
1145	0	9	62	21	41.5	2.5	120	0 %	Tap water flux
1150	5	-	62	21	41.5	2.5	108	0 %	City H2O trucked in, pH 8.7
1155	10	-	62	20	41	2.4	95	0 %	
1200	15	-	62	20	41	2.5	90	0 %	
1320	16	5	64	23	43.5	2.25	1750	0 %	Start MF conc. run
1335	30	5	64	23	43.5	2.25	1720	2 %	
1350	45	5.5	64	23	43.5	2.25	1690	3 %	
1420	75	6.5	64	23	43.5	2.25	1620	7 %	
1450	105	7	64	23	43.5	2.15	1550	11 %	
1520	195	7.5	64	23	43.5	2.1	1490	15 %	
1550	225	8.5	64	23	43.5	2.25	1410	19 %	
1620	255	9	63	22	42.5	2.25	1370	21 %	
1650	285	10	63	22	42.5	2.1	1290	26 %	Conc, colour green->orange, oxygenated?
1720	315	10.5	63	22	42.5	2.25	1215	30 %	Shut down 1730
945	316	9	64	22	43	2.75	1190	31 %	Continue conc. Oct 11
1000	330	9	64	22	43	2.6	-	-	
1015	345	9.5	64	22	43	2.5	1125	35 %	
1045	375	10.5	64	22	43	2.5	1040	40 %	
1115	405	11.5	64	22	43	2.5	960	44 %	
1145	435	12	64	22	43	2.5	900	48 %	
1215	465	13	63	22	42.5	2.4	810	53 %	conc. flow ~~145 LPM ~~38USGPM
1245	495	14.5	63	22	42.5	2.4	750	56 %	
1315	525	16.5	63	22	42.5	2.5	660	61 %	
1415	555	19	63	22	42.5	2.5	510	69 %	
1445	585	20	63	22	42.5	2.5	420	75 %	
1515	615	21.5	62	22	42	2.6	360	78 %	
1545	645	23.5	63	22	42.5	2.6	275	83 %	
1615	675	25	63	22	42.5	2.7	225	85 %	System auto shut off @ 1641, 160 L
1640	700	26	60	21	40.5	2.5	180	88 %	Collect 650 L MF perm for RO run

Table C-3 : Field Data Log Sheet

Application : Leachate Treatment
System : Microfiltration
Test No. 6 / 7

Type : Concentration to 90% Recovery
Pretreatment : Lime/Soda Ash to pH 10

Date: Oct 17'89

Real Time	Elapsed Time (min)	Temp. (°C)	Membrane Pressure Pin (psig)	Pout (psig)	Pave (psig)	Permeate Rate (LPM)	Tank Level (L)	Volume Reduction (%)	Comments
1130	0	12.5	64	23	43.5	5.75	1770	0 %	
1145	15	13.0	64	23	43.5	5.5	-	0 %	
1200	30	13.0	64	22	43	5.5	1770	0 %	
1215	45	13.5	64	22	43	5.5	1680	7 %	
1230	60	13.5	64	23	43.5	5.25	1620	10 %	
1245	75	13.5	64	22	43	5.1	1530	15 %	
1300	90	14.0	64	22	43	5	1455	19 %	
1315	105	14.0	64	22	43	4.8	1385	23 %	
1325	115	14.0	64	22	43	4.75	1330	26 %	start RO
1330	120	14.5	64	22	43	4.75	1300	28 %	
1345	135	14.5	64	22	43	4.7	1250	31 %	
1400	150	15.0	64	22	43	4.5	1170	35 %	
1430	180	15.5	64	22	43	4.5	-	-	
1500	210	16.0	64	22	43	4.3	930	48 %	
1530	240	16.5	64	22	43	4.25	790	56 %	
1545	255	17.0	64	22	43	4.2	720	60 %	shut down 1545
1100	255	8.0	63	22	42.5	4.75	720	60 %	start up Oct 18
1110	265	8.0	63	22	42.5	4.5	720	60 %	stability for 10 min
1120	275	9.0	62	22	42	4.5	700	61 %	continue conc
1130	285	9.5	62	22	42	4.5	640	65 %	
1145	300	10.0	62	22	42	4.25	570	68 %	
1200	315	10.5	62	22	42	4	535	70 %	conc flow (15L/6.8s) ~ 132 LPM
1230	345	12.0	62	22	42	3.9	370	80 %	
1300	375	13.5	62	22	42	3.85	280	84 %	
1325	400	15.0	62	22	42	3.85	180	90 %	final samples taken
1115	401	9.0	62	22	42	4.85	1800	47 %	total feed = 3455 L
1130	415	9.5	62	22	42	4.6	1750	48 %	
1145	430	9.5	62	22	42	4.25	1680	50 %	
1245	490	10.5	62	22	42	3.65	1440	57 %	
1300	505	11.0	62	22	42	3.65	1390	59 %	start RO
1315	520	11.0	62	21	41.5	3.6	1350	60 %	
1330	535	11.0	61	21	41	3.5	1290	62 %	
1400	565	12.0	60	20	40	3.3	1180	65 %	
1430	595	12.0	60	20	40	3.3	1085	68 %	
1500	625	13.5	60	20	40	3.25	995	70 %	
1530	655	14.5	60	20	40	3.25	900	73 %	

Test No. 6/7, page 2

Oct 17'89

Real Time	Elapsed Time (min)	Temp. (°C)	Membrane Pressure			Permeate Rate (LPM)	Tank Level (L)	Volume Reduction (%)	Comments
			Pin (psig)	Pout (psig)	Pave (psig)				
1600	685	15.0	60	20	40	3.15	810	76 %	stop at 720 L, min. vol. for mixer
1630	715	15.5	60	20	40	3.1	720	78 %	
1000	716	8.5	59	21	40	4.5	720	78 %	restart continue Oct 20
1015	730	9.0	50	18	34	3.4	640	80 %	conc. flow~117 LPM
1030	745	10.0	53	18	35.5	3.25	600	82 %	TSS=?
1050	765	11.0	43	14	28.5	2.5	540	83 %	
1051	766	11.0	50	27	38.5	3.5	-	-	conc. flow ~94LPM
1100	775	11.0	49	25	37	3.25	520	84 %	
1130	805	12.5	47	27	37	3.25	420	87 %	
1200	835	14.5	46	24	35	3	330	89 %	
1230	865	16.0	46	24	35	3	255	92 %	
1300	895	18.0	41	22	31.5	2.75	175	94 %	final samples taken @ 1310, 150L volume

Table C-4 : Field Data Log Sheet

Application : Leachate Treatment
System : Microfiltration
Test No. 8
Type : Concentration to 95% Recovery
Pretreatment : Lime/Soda Ash to pH 10
Date: Oct 23'89

Real Time	Elapsed Time (min)	Temp. (°C)	Membrane Pressure			Permeate Rate (LPM)	Tank Level (L)	Volume Reduction (%)	Comments
			Pin (psig)	Pout (psig)	Pave (psig)				
1015	0	7.5	60	20	40	6.5	-	0 %	
1030	15	10.5	59	20	39.5	6.3	-	0 %	
1045	30	13.0	59	20	39.5	6.75	-	0 %	Water flux
1100	45	15.0	59	20	39.5	6.75	-	0 %	
1115	60	16.5	59	20	39.5	7	-	0 %	
1145	90	19.0	58	19	38.5	7.4	-	0 %	
1215	120	22.5	58	21	39.5	7.5	-	0 %	
1415	121	17.0	62	27	44.5	6.5	1880	0 %	Test 8 start
1430	135	17.0	62	27	44.5	6	1780	5 %	
1445	150	17.5	62	27	44.5	5.75	1690	10 %	
1500	165	18.0	56	24	40	5.75	1590	15 %	
1515	180	18.0	55	24	39.5	5.5	1500	20 %	
1530	195	18.0	53	22	37.5	5.5	1425	24 %	
915	196	14.0	56	24	40	6.25	-	24 %	
930	210	14.5	55	24	39.5	5.6	1290	31 %	start RO
945	225	15.0	53	19	36	5.1	1210	36 %	
1000	240	15.5	52	19	35.5	4.9	1130	40 %	perm cond. 2500 µS/cm
1030	270	16.5	52	18	35	4.6	1000	47 %	
1045	285	17.0	52	18	35	4	940	50 %	
1130	330	17.0	50	18	34	3.8	1830	34 %	added 890 L feed total feed 2770 L
1200	360	18.0	53	20	36.5	4.4	1700	39 %	
1230	390	18.5	53	20	36.5	4.1	1590	43 %	
1300	420	19.5	53	20	36.5	4	1470	47 %	MF perm cond. 2700 µS/cm
1330	450	20.0	53	19	36	3.85	1340	52 %	
1400	480	21.0	52	19	35.5	3.75	1230	56 %	
1430	510	22.0	52	18	35	3.75	1120	60 %	
1500	540	22.5	52	18	35	3.65	1020	63 %	MF perm cond. 2700 µS/cm
1530	570	23.0	52	18	35	3.65	910	67 %	
1615	615	21.5	52	19	35.5	3.4	1845	50 %	added 945 L feed total feed 3715 L
1630	630	22.0	52	19	35.5	3.5	1800	52 %	MF perm cond. 2500 µS/cm
1700	660	22.0	52	18	35	3.4	1690	55 %	
1015	661	17.0	56	20	38	4.5	1620	56 %	perm cond. 2600 µS/cm
1030	675	17.5	56	20	38	4.5	1575	58 %	
1045	690	18.0	56	19	37.5	4.25	1515	59 %	perm cond. 2600 µS/cm
1100	705	18.0	55	19	37	4	1440	61 %	
1115	720	18.5	54	18	36	3.8	1395	62 %	

Test No. 8, page 2 **Oct 23'89**

Real Time	Elapsed Time (min)	Temp. (°C)	Membrane Pressure			Permeate Rate (LPM)	Tank Level (L)	Volume Reduction (%)	Comments
			Pin (psig)	Pout (psig)	Pave (psig)				
1145	750	19.0	54	18	36	3.6	1280	66 %	
1215	751	19.5	53	18	35.5	3.5	1180	68 %	perm cond. 2600 µS/cm
1245	810	20.0	53	18	35.5	3.5	1080	71 %	
1315	840	21.0	53	18	35.5	3.4	975	74 %	conc. flow 121 lpm = 32 usgpm
1345	870	22.0	53	18	35.5	3.4	880	76 %	
1445	930	21.0	53	19	36	3.2	1780	61 %	perm cond. 2600 µS/cm
1515	960	21.5	56	20	38	3.5	1680	64 %	total feed 4615 L
1545	990	22.0	56	20	38	3.5	1580	66 %	
1615	1020	22.0	56	20	38	3.5	1480	68 %	perm cond. 2600 µS/cm
1645	1050	23.0	56	20	38	3.4	1390	70 %	
1715	1080	23.5	56	20	38	3.4	1280	72 %	
945	1081	18.0	57	20	38.5	4	1250	73 %	restart, recirculate while RO tank level
1015	1110	19.0	56	20	38	3.75	1250	73 %	lowers, to accomodate more feed
1045	1140	19.5	56	20	38	3.6	1250	73 %	
1115	1170	20.0	56	20	38	3.5	1250	73 %	start conc., perm cond. = 2700 µS/cm
1145	1200	21.0	56	20	38	3.5	1140	75 %	
1215	1230	21.5	56	20	38	3.5	1030	78 %	conc. flow 136 lpm = 40 usgpm
1245	1260	22.5	56	20	38	3.5	940	80 %	
1300	1275	23.0	56	20	38	3.5	880	81 %	MF perm to drain, allow RO to conc.
1315	1290	24.0	56	20	38	3.5	860	81 %	
1345	1320	24.5	56	20	38	3.5	750	84 %	
1415	1321	25.5	55	19	37	3.5	650	86 %	
1445	1380	27.0	55	19	37	3.5	550	88 %	
1515	1410	28.0	55	19	37	3.4	460	90 %	
1545	1440	29.5	55	19	37	3.4	360	92 %	MF perm cond. =2700
1615	1470	31.0	54	18	36	3.5	180	96 %	
1640	1495	33.0	48	16	32	3.1	180	96 %	
1645	1500	33.0	48	16	32	3.1	180	96 %	
1700	1515	33.5	48	16	32	3.1	180	96 %	
1715	1530	34.0	48	16	32	3.2	180	96 %	
1730	1545	35.0	48	16	32	3.1	180	96 %	

Table C-5 : Field Data Log Sheet

Application : Leachate Treatment
System : Microfiltration **Type :** Concentration to 80% Recovery
Test No. 10 **Pretreatment :** Lime to pH 8 **Date:** Nov 1'89

Real Time	Elapsed Time (min)	Temp. (°C)	Membrane Pressure Pin (psig)	Membrane Pressure Pout (psig)	Membrane Pressure Pave (psig)	Permeate Rate (LPM)	Tank Level (L)	Volume Reduction (%)	Comments
1100	0	7.0	56	20	38	4.4	1720	0%	total feed incl. hold-up = 1755, cond 2200
1115	15	7.5	56	20	38	4.4	-	0%	pH 6.6, add 750g lime to pH 8.0
1130	30	7.5	56	20	38	4.25	1620	6%	NO soda ash added
1145	60	8.0	56	20	38	4.1	1620	6%	
1200	90	8.0	56	20	38	3.9	1545	10%	
1230	120	8.5	56	19	37.5	3.8	1440	16%	
1300	150	9.0	56	19	37.5	3.75	1300	24%	
1330	180	10.0	55	18	36.5	3.75	1200	30%	cond. 1050 µS/cm
1400	210	10.5	55	18	36.5	3.75	1080	36%	conc flow 125 lpm
1430	240	11.5	55	18	36.5	3.75	975	42%	
1500	270	12.0	55	18	36.5	3.7	875	48%	cond. 1000 µS/cm
1600	330	10.5	56	19	37.5	3.4	1770	32%	900 L feed pumped up
1630	360	11.0	55	19	37	3.5	1695	35%	cond. 1100 µS/cm
820	361	6.0	55	20	37.5	4.25	1690	35%	
830	370	7.0	55	19	37	4.1	1690	35%	
900	390	7.5	55	19	37	4.1	1560	40%	perm cond. 1025 µS/cm
930	420	8.0	54	19	36.5	4	1440	44%	
1000	450	8.5	54	18	36	3.75	1320	49%	
1030	480	9.0	54	18	36	3.75	1220	53%	
1100	510	10.0	53	18	35.5	3.6	1090	58%	perm cond. 960 µS/cm
1130	540	11.0	53	17	35	3.5	990	61%	conc flow 120 lpm
1200	570	11.5	53	17	35	3.5	890	65%	stabilty while filling, 930 L added
1300	630	8.0	54	18	36	3.25	1790	49%	perm cond. 1100 µS/cm
1330	660	9.0	54	18	36	3.25	1680	52%	
1400	690	9.0	54	18	36	3.25	1580	55%	
1430	720	10.0	54	18	36	3.25	1480	58%	
1500	750	10.5	54	18	36	3.2	1410	60%	perm cond. 1000 µS/cm
1530	780	11.0	53	17	35	3.1	1310	62%	
1600	810	11.5	54	18	36	3.1	1220	65%	
1630	839	12.0	53	17	35	3.1	1125	68%	
900	840	6.0	54	19	36.5	4	1125	68%	stability while RO tank lowers
930	845	-	54	19	36.5	3.75	1125	68%	perm cond. 950 µS/cm
1000	870	8.0	54	18	36	3.75	1020	71%	
1030	900	-	53	18	35.5	3.75	900	74%	stability while filling
1130	960	8.5	53	19	36	3.25	1850	58%	950 L added, 400 g lime to pH 8.1
1200	990	9.0	53	19	36	3.3	1730	61%	perm cond. 1075

Test No. 10, page 2 Nov 1'89

Real Time	Elapsed Time (min)	Temp. (°C)	Membrane Pressure Pin (psig)	Membrane Pressure Pout (psig)	Membrane Pressure Pave (psig)	Permeate Rate (LPM)	Tank Level (L)	Volume Reduction (%)	Comments
1230	1020	9.0	53	18	35.5	3.25	1630	63%	
1300	1050	9.0	52	19	35.5	3.2	1540	65%	perm cond 1040
1330	1080	10.0	52	18	35	3.1	1450	67%	perm to drain (130 L)
1415	1125	10.0	52	17	34.5	3	1320	70%	
1430	1140	10.5	52	17	34.5	3	1320	70%	perm cond. 1000
1500	1170	11.0	52	17	34.5	3	1220	72%	
1530	1200	11.5	52	17	34.5	3	1130	74%	
1600	1230	12.0	52	17	34.5	3	1050	76%	stability (RO tank 620 L)
1630	1260	12.0	52	17	34.5	3	1050	76%	per cond. 980
1030	1260	4.0	55	20	37.5	3.7	1050	76%	stability while RO level drops
1100	1260	5.0	54	18	36	3.3	1050	76%	
1130	1260	6.0	53	17	35	3.2	1050	76%	restart conc., perm cond 960 µS/cm
1200	1290	7.0	52	17	34.5	3.1	945	78%	
1230	1320	8.0	52	17	34.5	3.1	850	80%	
1300	1350	8.5	52	17	34.5	3.1	770	82%	stability
1330	1380	9.5	50	16	33	2.9	770	82%	perm cond. 960
1400	1410	10.0	50	16	33	2.9	770	82%	
1430	1440	10.5	50	16	33	2.9	770	82%	
1500	1470	11.0	50	16	33	2.9	770	82%	

Table C-6 : Field Data Log Sheet

Application : Leachate Treatment
System : Microfiltration **Type :** **Concentration to 75% Recovery**
Test No. 11 **Pretreatment :** **Lime to pH 8** **Date:** **Nov 8'89**

Real Time	Elapsed Time (min)	Temp. (°C)	Membrane Pressure Pin (psig)	Pout (psig)	Pave (psig)	Permeate Rate (LPM)	Tank Level (L)	Volume Reduction (%)	Comments
1200	0	-	56	19	37.5	3.5	1760	0%	raw pH 6.6, 1000g lime->pH 8.7
1230	30	6.0	56	19	37.5	3.4	-	0%	perm cond 1250 µS/cm
1300	60	6.5	55	19	37	3.4	1550	12%	perm cond 1150 µS/cm
1330	90	7.5	55	19	37	3.25	1520	14%	perm cond 1075 µS/cm, pH 8.3
1400	120	8.0	55	19	37	3.25	1425	19%	perm cond 1040 µS/cm, pH 8.3
1430	150	8.5	55	18	36.5	3.25	1320	25%	
1500	180	9.0	55	18	36.5	3.25	1230	30%	perm cond 950 µS/cm
1530	210	10.0	55	18	36.5	3.25	1120	36%	
1600	240	10.5	54	17	35.5	3.2	1035	41%	
1630	270	11.0	54	17	35.5	3.2	950	45%	perm cond 900 µS/cm
930	271	8.0	54	19	36.5	3.9	950	45%	
945	285	8.0	54	19	36.5	3.9	900	48%	both MF & RO stability while filling
1045	345	8.5	53	19	36	3.5	1850	31%	MF tank
1100	360	8.5	53	19	36	3.75	1800	33%	added 950 L feed, pH 6.75
1120	380	9.0	53	19	36	3.5	1710	37%	total MF feed 2750 L, perm cond 1060
1200	420	10.0	53	18	35.5	3.4	1710	37%	
1230	450	10.0	53	18	35.5	3.4	1710	37%	perm cond 960
1300	480	10.5	53	18	35.5	3.5	1620	40%	
1330	510	11.0	53	18	35.5	3.5	1510	44%	
1340	520	11.5	53	18	35.5	3.5	1470	45%	
1400	540	12.0	53	18	35.5	3.5	1400	48%	perm cond 930
1430	570	12.0	52	18	35	3.35	1310	51%	
1500	600	13.0	52	18	35	3.25	1310	51%	
1530	630	13.5	52	18	35	3.25	1310	51%	
1600	660	14.0	52	18	35	3.25	1220	54%	perm cond 910
1000	671	9.0	55	19	37	4	1200	55%	perm cond. 925 µS/cm
1030	700	-	54	19	36.5	4	1130	58%	
1100	730	10.5	54	19	36.5	3.9	1010	62%	
1130	760	11.0	54	19	36.5	3.75	900	66%	both units stability while filling
1230	790	10.0	54	19	36.5	3.5	1830	49%	930 L added, total feed 3680 L
1300	820	11.0	54	19	36.5	3.5	1710	53%	perm cond. 1100 µS/cm
1330	850	11.5	54	19	36.5	3.5	1620	55%	
1400	880	12.0	54	19	36.5	3.5	1515	58%	perm cond. 1050 µS/cm
1430	910	12.0	54	18	36	3.5	1410	61%	

Test No. 11, page 2 Nov 8'89

Real Time	Elapsed Time (min)	Temp. (°C)	Membrane Pressure			Permeate Rate (LPM)	Tank Level (L)	Volume Reduction (%)	Comments
			Pin (psig)	Pout (psig)	Pave (psig)				
1500	940	12.5	54	18	36	3.4	1310	63%	perm cond. 1020 µS/cm
1530	970	13.0	54	18	36	3.4	1215	66%	
1600	1000	14.0	54	18	36	3.4	1120	69%	
830	1001	7.5	54	19	36.5	3.75	1120	69%	stability - RO @ 80 %
900	1030	8.0	54	19	36.5	3.75	-	69%	
930	1060	8.0	54	19	36.5	3.75	-	69%	
1000	1090	8.5	54	19	36.5	3.5	-	69%	
1030	1120	9.0	54	19	36.5	3.5	-	69%	total RO feed 2445 L
1100	1150	10.0	54	19	36.5	3.4	-	69%	
1130	1180	10.5	54	19	36.5	3.4	1120	69%	start conc RO to 85 %
1200	1210	11.0	54	18	36	3.4	1035	71%	
1230	1240	11.5	53	18	35.5	3.4	940	74%	
1300	1270	12.0	53	18	35.5	3.4	880	75%	Total RO feed 2685 L

Table C-7 : Field Data Log Sheet

Application : Leachate Treatment
System : Microfiltration
Test No. 12
Type : Concentration to 75% Recovery
Pretreatment : Lime to pH 8
Date: Nov 13'89

Real Time	Elapsed Time (min)	Temp. (°C)	Membrane Pressure Pin (psig)	Pout (psig)	Pave (psig)	Permeate Rate (LPM)	Tank Level (L)	Volume Reduction (%)	Comments
1120	0	5.0	60	21	40.5	4	1740	0%	total MF feed 1775 L
1140	20	5.5	60	21	40.5	4	1660	5%	pH 6.6 + 850g lime -> pH 8.0
1200	40	6.0	60	21	40.5	3.85	1570	10%	perm cond 1400
1230	70	7.0	60	21	40.5	3.75	1460	16%	perm cond 1330
1300	100	7.5	59	20	39.5	3.75	1350	22%	
1330	130	8.8	59	20	39.5	3.8	1240	28%	perm cond 1200
1400	160	-	59	20	39.5	3.8	1125	35%	perm cond 1130
1430	190	10.0	59	20	39.5	3.8	1005	41%	perm cond 1100
1500	220	11.0	59	20	39.5	3.8	900	47%	
930	221	10.0	58	21	39.5	4.25	1790	32%	added 900 L - total feed 2675 L
1000	250	10.0	58	21	39.5	4.4	1700	35%	350 g lime to pH 8.1, perm cond 1175
1030	280	10.5	58	20	39	4.2	1575	40%	perm cond 1120
1100	310	11.0	58	20	39	4.1	1455	44%	perm cond 1100
1130	340	12.0	58	20	39	4	1340	49%	
1200	370	12.5	58	20	39	4	1220	53%	stability while RO level drops
1230	400	13.0	58	20	39	3.75	1220	53%	
1300	430	14.0	58	20	39	3.9	1090	58%	
1330	460	14.5	58	20	39	3.9	1000	61%	perm cond 1050
1400	490	15.0	58	20	39	3.9	885	66%	
1430	520	16.0	58	20	39	3.9	770	70%	perm cond 1020
1500	550	17.0	57	20	38.5	3.9	650	74%	
1510	560	17.5	57	20	38.5	3.9	610	76%	no more MF perm fed to RO, all of the 50%

Appendix D

Reverse Osmosis

Test Data

FIGURE D-1
Reverse Osmosis System Operation - Pilot Test #5

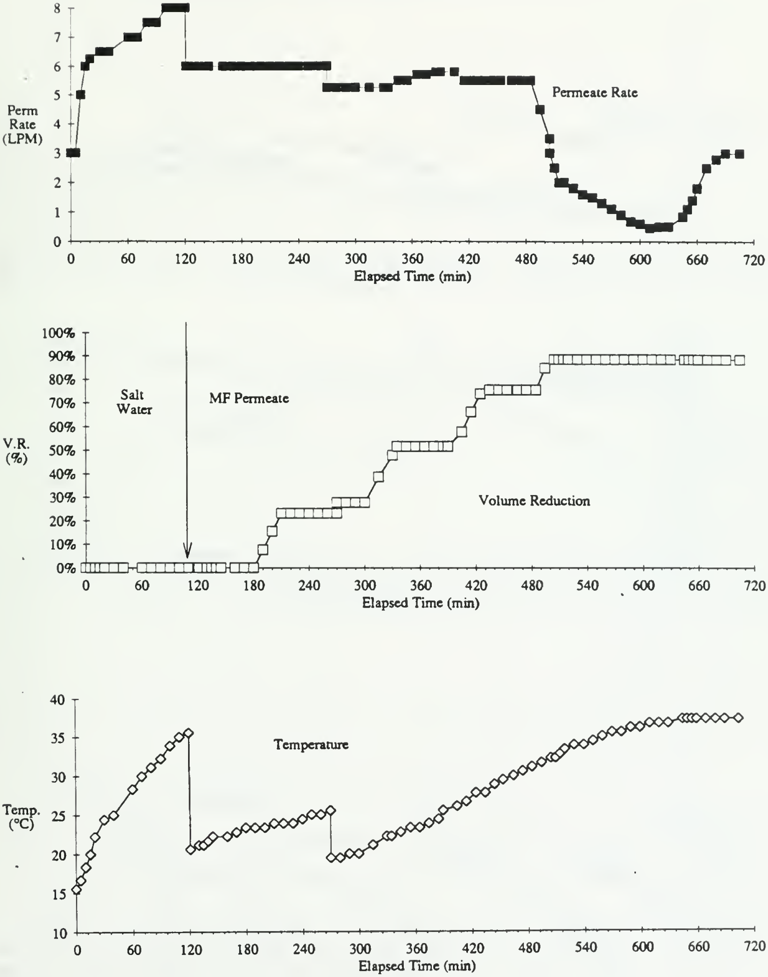

FIGURE D-2
Reverse Osmosis System Operation - Pilot Test #6/7

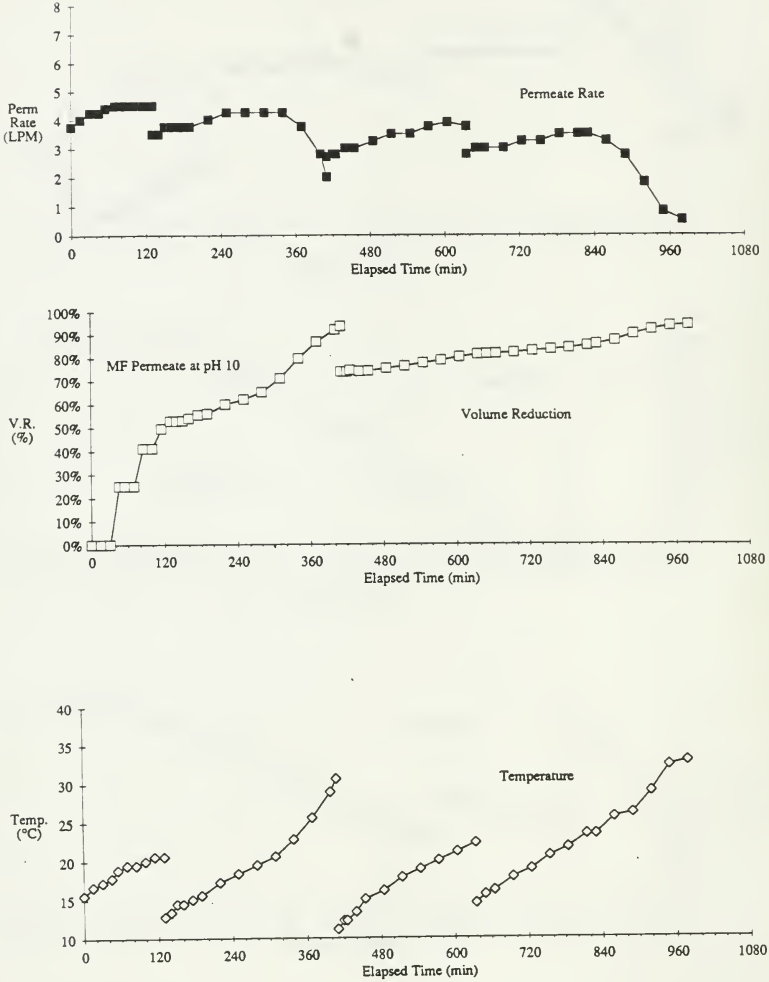

FIGURE D-3
Reverse Osmosis System Operation - Pilot Test #10

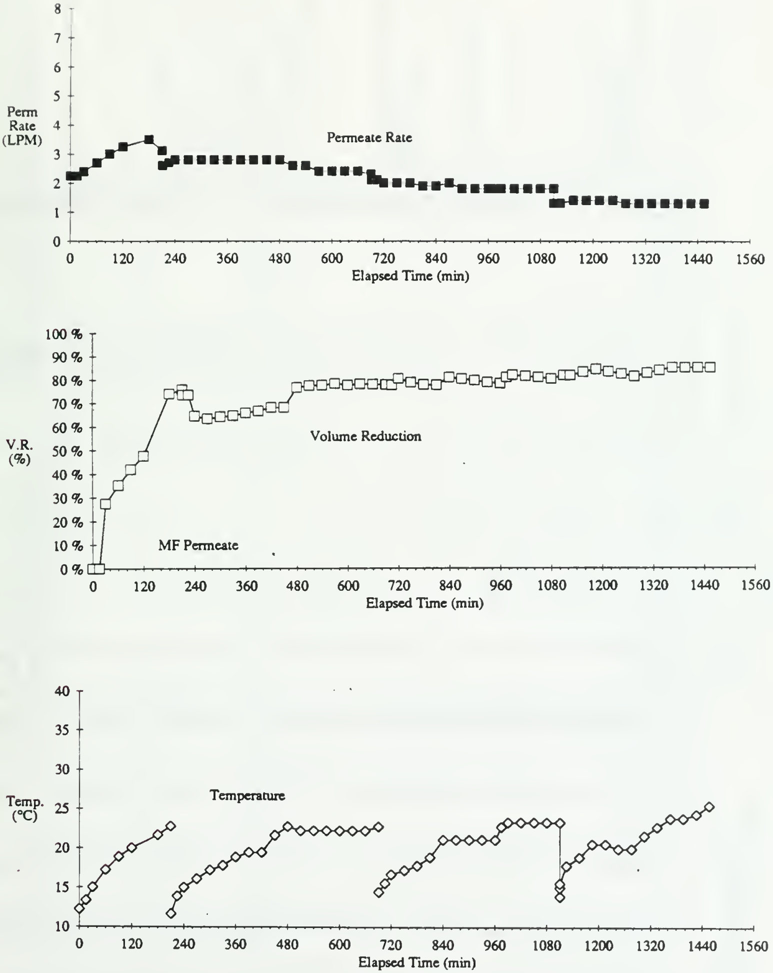

Table D-1

Application : Leachate Treatment
System: Reverse Osmosis
Test No. 5

Type: Stability at 0%, 25%, 50%, 75%, 90%
Pretreatment : None

Date: Oct 11'89

Real Time	Elapsed Time (min)	Temp. (°F)	Temp. (°C)	Membrane PI (psig)	Filter Pressure (psig)	Conc. Rate (LPM)	Permeate Rate (LPM)	Cond. (µS/cm)	Rejection (%)	Tank Level (L)	Volume Reduction (%)	Comments
1400	0	60	16	400	0	3	3	165	97 .5%	-	0%	Baseline saltwater flux (test #2)
1405	5	62	17	400	0	3	3	161	-	-	0%	~2000 ppm NaCl
1410	10	65	18	400	0	2.5	5	160	97 .6%	-	0%	(72g NaCl/~36L RO water)
1415	15	68	20	400	0	2.25	6	158	-	-	0%	
1420	20	72	22	400	0	2	6.25	150	97 .7%	-	0%	Feed cond. = 6600 µS/cm
1430	30	76	24	400	0	2	6.5	145	97 .8%	-	0%	
1440	40	77	25	400	0	2	6.5	144	-	-	0%	
1500	60	83	28	400	0	too low	7	145	-	-	0%	
1510	70	86	30	400	0	to	7	146	97 .8%	-	0%	
1520	80	88	31	400	0	measure	7.5	146	-	-	0%	
1530	90	90	32	400	0	-	7.5	146	-	-	0%	Sun warming cooling lines
1540	100	93	34	400	0	-	8	145	97 .8%	-	0%	
1550	110	95	35	400	0	-	8	146	-	-	0%	
1600	120	96	36	400	0	-	8	144	97 .8%	-	0%	
1645	121	69	21	400	65	14	6	140	94 .6%	630	0%	feed cond.=3400
1655	130	70	21	400	64	14	6	143	94 .5%	-	0%	stability
1700	135	70	21	400	64	14	6	144	94 .5%	-	0%	RO permeate has ammonia odor
1705	140	71	22	400	64	14	6	144	94 .5%	-	0%	
1710	145	72	22	400	64	13.5	6	144	94 .5%	-	0%	
1725	160	72	22	400	64	13.5	6	145	94 .4%	-	0%	
1735	170	73	23	400	64	13.5	6	145	94 .4%	-	0%	
1745	180	74	23	400	64	13.5	6	145	94 .4%	-	0%	
1755	190	74	23	400	64	13.5	6	146	94 .4%	580	8%	
1805	200	74	23	400	64	13.5	6	149	94 .3%	530	15%	
1815	210	75	24	400	64	13.5	6	150	94 .2%	480	23%	conc. cond.=4300
1815	210	75	24	400	64	13.5	6	150	94 .2%	480	23%	conc. cond.=4300
1825	220	75	24	400	64	13.5	6	152	94 .2%	-	23%	HACH cond.=128 µS/cm
1835	230	75	24	400	64	13.5	6	152	94 .2%	-	23%	stability
1845	240	76	24	400	64	13.5	6	153	94 .1%	-	23%	
1855	250	77	25	400	64	13.5	6	153	94 .1%	-	23%	
1905	260	77	25	400	64	13.5	6	154	94 .1%	-	23%	
1915	270	78	26	400	64	13.5	6	155	94 .0%	480	23%	
900	270	67	19	400	64	14	5.25	144	94 .5%	470	28%	stability
910	280	67	19	400	64	14	5.25	144	94 .5%	-	28%	
920	290	68	20	400	64	14	5.25	146	94 .4%	-	28%	
930	300	68	20	400	64	14	5.25	147	94 .3%	-	28%	
945	315	70	21	400	64	14	5.25	147	94 .3%	400	38%	
1000	330	72	22	400	64	14	5.25	154	94 .1%	340	48%	
1005	335	72	22	400	64	14	5.25	155	94 .0%	315	52%	conc. cond.=6000
1010	345	73	23	400	64	14	5.5	159	93 .9%	-	52%	
1020	355	74	23	400	64	14	5.5	160	93 .8%	-	52%	
1030	365	74	23	400	64	14	5.7	161	93 .8%	-	52%	

Real Time	Elapsed Time (min)	Temp. (°F)	Temp. (°C)	Membrane PI (psig)	Filter Pressure (psig)	Conc. Rate (LPM)	Permeate Rate (LPM)	Cond. (µS/cm)	Rejection (%)	Tank Level (L)	Volume Reduction (%)	Comments
1040	375	75	24	400	64	14	5.7	160	93.8%	-	52%	stability
1050	385	76	24	400	64	14	5.8	159	93.9%	-	52%	
1100	390	78	26	400	64	13.5	5.8	160	93.8%	315	52%	
1110	405	79	26	400	64	13	5.8	163	93.7%	275	58%	
1120	415	80	27	400	64	13	5.5	168	93.5%	220	66%	
1130	425	82	28	400	64	13.5	5.5	175	93.3%	170	74%	
1140	435	82	28	400	64	13.5	5.5	178	93.2%	160	75%	conc cond.=9200
1150	445	84	29	400	64	13.5	5.5	181	93.0%	-	75%	stability
1200	454	85	29	400	64	13.5	5.5	183	93.0%	-	75%	
1210	465	86	30	400	64	13.5	5.5	185	92.9%	-	75%	
1220	475	87	31	400	64	13.5	5.5	185	92.9%	-	75%	
1230	485	88	31	400	64	13.5	5.5	186	92.8%	160	75%	
1240	495	89	32	400	64	13.5	4.5	-	-	100	85%	stability
1250	505	90	32	400	64	14	3.5	-	-	75	88%	conc. cond.=12800
1255	505	90	32	420	64	14	3	-	-	75	88%	conc. cond.=12800
1300	510	90	32	400	64	17	2.5	310	88.1%	-	88%	cond. measured by HACH
1305	515	91	33	400	64	17	2	-	-	-	88%	
1310	520	92	33	400	64	17	2	-	-	-	88%	
1320	530	93	34	400	64	17.5	1.8	-	-	-	88%	
1330	540	93	34	400	64	18	1.6	-	-	-	88%	
1340	550	94	34	400	64	18	1.5	-	-	-	88%	Permeate drop due to air?
1350	560	95	35	400	64	18.5	1.3	-	-	-	88%	
1400	570	96	36	400	64	18.5	1.1	-	-	-	88%	
1410	580	96	36	400	64	19	0.9	-	-	-	88%	
1420	590	97	36	400	64	19	0.67	-	-	-	88%	
1430	600	97	36	400	64	19	0.6	-	-	-	88%	
1440	610	98	37	400	64	20	0.45	-	-	-	88%	
1450	620	98	37	400	61	20	0.5	-	-	-	88%	
1500	630	98	37	400	60	20	0.5	520	80.0%	-	88%	conc cond.=12200
1515	645	99	37	400	59	20	0.85	-	-	-	88%	
1520	650	99	37	400	59	19.5	1.1	-	-	-	88%	
1525	655	99	37	400	59	19.5	1.4	-	-	-	88%	
1530	660	99	37	400	59	19.5	1.8	-	-	-	88%	
1540	670	99	37	400	58	18.5	2.5	-	-	-	88%	
1550	680	99	37	400	59	18	2.8	-	-	-	88%	
1600	690	99	37	400	59	18	3	270	89.6%	-	88%	
1615	705	99	37	400	59	18	3	-	-	-	88%	

Table D-2

Application : Leachate Treatment
System: Reverse Osmosis
Test No. 6

Type: Concentration to 95%
Pretreatment : None

Date: Oct 17'89

Real Time	Elapsed Time (min)	Temp. (°F)	Temp. (°C)	Membrane Pl (psig)	Filter Pressure (psig)	Conc. Rate (LPM)	Permeate Rate (LPM)	Cond. (µS/cm)	Rejection (%)	Tank Level (L)	Volume Reduction (%)	Comments
1325	0	60	16	400	62	15.5	3.75	111	95.6%	420	0%	perm. pH 10.8
1340	15	62	17	400	64	15	4	115	95.4%	425	0%	
1355	30	63	17	390	64	15	4.25	121	95.2%	445	0%	perm. pH 10.9
1410	45	64	18	400	64	14.5	4.25	125	95.0%	450	25%	MF perm cond.= 2500
1430	55	66	19	400	64	14.5	4.4	130	94.8%	465	25%	
1445	70	67	19	400	64	14.5	4.5	133	94.7%	470	25%	
1500	85	67	19	400	64	14.5	4.5	136	94.6%	475	41%	
1515	100	68	20	400	64	14.5	4.5	138	94.5%	475	41%	perm. sample for HACH cond.
1530	115	69	21	400	64	14.5	4.5	141	94.4%	475	49%	
1545	130	69	21	400	64	14	4.5	143	94.3%	475	53%	shut down 1545
1100	130	55	13	400	64	16	3.5	137	94.5%	475	53%	start up 1100 Oct 18
1110	140	56	13	400	64	16	3.5	137	94.5%	475	53%	RO conc. cond. =5500
1120	150	58	14	400	64	15.5	3.75	138	94.5%	-	53%	
1130	160	58	14	400	64	15.5	3.75	140	94.4%	500	54%	
1145	175	59	15	400	64	15	3.75	142	94.3%	515	55%	
1200	190	60	16	400	64	15	3.75	143	94.3%	525	56%	
1230	220	63	17	400	64	15	4	146	94.2%	540	60%	
1300	250	65	18	400	64	14.5	4.25	150	94.0%	545	62%	
1330	280	67	19	400	64	14.5	4.25	153	93.9%	545	65%	MF shut down
1400	310	69	21	400	64	15	4.25	159	93.6%	450	71%	
1430	340	73	23	400	64	14.5	4.25	175	93.0%	310	80%	
1500	370	78	26	400	64	15	3.75	-	-	195	87%	
1530	400	84	29	410	64	15.5	2.8	-	-	110	92%	total RO feed 1590 L
1540	410	87	31	400	64	16.5	2	300	88.0%	85	94%	RO perm (HACH) cond.= 300
1245	410	52	11	400	64	18	2.7	-	-	500	74%	
1255	420	54	12	400	64	17	2.8	167	93.0%	500	74%	79.8% conc.
1300	425	54	12	400	64	17	2.8	161	93.3%	500	74%	MF perm cond.=2400
1315	440	56	13	400	64	16	3	153	93.6%	520	74%	RO feed cond.=8700
1330	455	59	15	400	64	15.5	3	155	93.5%	530	74%	
1400	485	61	16	400	64	15	3.25	157	93.5%	535	75%	
1430	515	64	18	400	64	15	3.5	159	93.4%	535	76%	
1500	545	66	19	400	64	15	3.5	162	93.3%	525	78%	
1530	575	68	20	400	65	15	3.75	165	93.1%	520	79%	
1600	605	70	21	400	64	15	3.9	170	92.9%	500	80%	
1630	635	72	22	400	64	15	3.75	176	92.7%	485	81%	shut down-total feed 2735 L
1000	635	58	14	400	64	16.5	2.8	165	93.1%	485	81%	restart Oct 20
1015	650	60	16	400	64	16.5	3	162	93.3%	495	81%	continue run
1030	665	61	16	400	64	16	3	162	93.3%	500	82%	

Test No. 6, page 2 Oct 17'89

Real Time	Elapsed Time (min)	Temp. (°F)	Temp. (°C)	Membrane P1 (psig)	Filter Pressure (psig)	Conc. Rate (LPM)	Permeate Rate (LPM)	Cond. (µS/cm)	Rejection (%)	Tank Level (L)	Volume Reduction (%)	Comments
1100	695	64	18	390	64	17	3	163	93 .2%	500	82%	
1130	725	66	19	400	64	15.5	3.25	162	93 .3%	500	83%	
1200	755	69	21	400	64	15.5	3.25	167	93 .0%	495	83%	
1230	785	71	22	400	65	15	3.5	172	92 .8%	485	84%	
1300	815	74	23	400	65	15.5	3.5	177	92 .6%	465	85%	
1315	830	74	23	400	65	15.5	3.5	181	92 .5%	450	86%	
1330	860	78	26	400	65	15.5	3.25	188	92 .2%	400	87%	
1400	890	79	26	405	64	16	2.75	-	-	310	90%	total feed 3270 L
1430	920	84	29	415	65	16	1.8	240	90 .0%	250	92%	perm cond.(HACH)= 240
1500	950	90	32	400	56	20	0.8	-	-	200	93%	MF perm cond.=2800
1530	980	91	33	400	46	20	0.5	440	81 .7%	185	94%	TDS=?

Table D-3

Application : Leachate Treatment
System: Reverse Osmosis
Test No. 7

Type: Concentrate to 95%
Pretreatment : None

Date: Oct 19/20'89

Real Time	Elapsed Time (min)	Temp. (°F)	Temp. (°C)	Membrane PI (psig)	Filter Pressure (psig)	Conc. Rate (LPM)	Permeate Rate (LPM)	Cond. (µS/cm)	Rejection (%)	Tank Level (L)	Volume Reduction (%)	Comments
1245	0	52	11	400	64	18	2.7	-	-	500	74%	total Ro feed 3270 L
1255	10	54	12	400	64	17	2.8	167	93 .0%	500	74%	79.8% conc.
1300	15	54	12	400	64	17	2.8	161	93 .3%	500	74%	MF perm cond.=2400
1315	30	56	13	400	64	16	3	153	93 .6%	520	74%	RO feed cond.=8700
1330	45	59	15	400	64	15.5	3	155	93 .5%	530	74%	
1400	75	61	16	400	64	15	3.25	157	93 .5%	535	75%	
1430	105	64	18	400	64	15	3.5	159	93 .4%	535	76%	
1500	135	66	19	400	64	15	3.5	162	93 .3%	525	78%	
1530	165	68	20	400	65	15	3.75	165	93 .1%	520	79%	
1600	195	70	21	400	64	15	3.9	170	92 .9%	500	80%	
1630	225	72	22	400	64	15	3.75	176	92 .7%	485	81%	shut down
1000	225	58	14	400	64	16.5	2.8	165	93 .1%	485	81%	restart Oct 20
1015	240	60	16	400	64	16.5	3	162	93 .3%	495	81%	continue run
1030	255	61	16	400	64	16	3	162	93 .3%	500	82%	
1100	285	64	18	390	64	17	3	163	93 .2%	500	82%	
1130	315	66	19	400	64	15.5	3.25	162	93 .3%	500	83%	
1200	345	69	21	400	64	15.5	3.25	167	93 .0%	495	83%	
1230	375	71	22	400	65	15	3.5	172	92 .8%	485	84%	
1300	405	74	23	400	65	15.5	3.5	177	92 .6%	465	85%	
1315	420	74	23	400	65	15.5	3.5	181	92 .5%	450	86%	
1330	450	78	26	400	65	15.5	3.25	188	92 .2%	400	87%	
1400	480	79	26	405	64	16	2.75	-	-	310	90%	
1430	510	84	29	415	65	16	1.8	240	90 .0%	250	92%	perm cond.(HACH)= 240
1500	540	90	32	400	56	20	0.8	-	-	200	93%	MF perm cond.=2800
1530	570	91	33	400	46	20	0.5	440	81 .7%	185	94%	TDS=?

Table D-4

Application : Leachate Treatment
System: Reverse Osmosis
Test No. 8

Type: **Stability at 80%, 90%**
Pretreatment : **None**

Date: **Oct 24'89**

Real Time	Elapsed Time (min)	Temp. (°F)	Temp. (°C)	Membrane PI (psig)	Filter Pressure (psig)	Conc. Rate (LPM)	Permeate Rate (LPM)	Cond. (µS/cm)	Rejection (%)	Tank Level (L)	Volume Reduction (%)	Comments
930	0	62	17	400	58	15	3.75	137	94 .7%	525	0%	recoveries based on feed
945	15	64	18	400	64	15	3.75	134	94 .8%	550	15%	conductivity 2600 µS/cm
1000	30	65	18	400	64	15	3.75	135	94 .8%	570	21%	cond. adj. 135->110 (HACH)
1030	60	67	19	400	65	14	4	112	95 .7%	600	30%	
1045	75	68	20	400	65	14	4	113	95 .7%	605	34%	
1115	105	71	22	400	65	14	4	119	95 .4%	490	34%	
1130	120	72	22	400	65	14	4	123	95 .3%	440	51%	MF perm 2600 µS/cm
1200	150	74	23	400	64	14.5	3.75	126	95 .2%	430	58%	cond. adj. 126->137 (HACH)
1320	180	75	24	400	64	14.5	3.75	139	94 .7%	450	60%	conc cond. 6200
1300	210	77	25	400	64	14.5	3.75	142	94 .5%	470	62%	
1330	240	78	26	400	65	15	3.75	144	94 .5%	480	65%	
1400	270	79	26	400	65	15	3.5	145	94 .4%	490	67%	
1430	300	80	27	400	65	15	3.5	148	94 .3%	500	68%	perm cond 158 (HACH)
1500	330	81	27	400	65	15	3.5	150	94 .2%	510	70%	conc. cond. 8000
1530	360	82	28	400	65	15.5	3.25	152	94 .2%	520	71%	
1600	390	84	29	400	65	15	3	160	93 .8%	430	71%	
1615	405	85	29	400	65	15	3	164	93 .7%	390	78%	conc cond. 10500
1630	420	86	30	400	65	15	2.75	163	93 .7%	390	79%	perm 180 (HACH)
1700	450	86	30	400	65	15.5	2.75	161	93 .8%	390	80%	
1015	451	69	21	400	64	17	2.75	290	88 .8%	-	79%	recoveries based on feed
1030	465	71	22	400	64	16	2.75	-	-	435	79%	conductivity of 2600 µS/cm
1045	480	72	22	400	64	16	2.75	260	90 .0%	455	78%	conc cond. 10,000
1100	495	73	23	400	64	16	2.75	260	90 .0%	480	78%	
1115	510	74	23	400	64	16	2.75	250	90 .4%	500	78%	
1145	540	75	24	400	65	15.5	2.7	275	89 .4%	530	77%	
1215	570	76	24	400	65	15.5	2.6	300	88 .5%	560	77%	conc cond. 9600
1245	600	76	24	400	65	15.5	2.6	340	86 .9%	585	77%	
1315	630	78	26	400	65	15.5	2.6	400	84 .6%	605	77%	
1345	660	79	26	400	65	15.5	2.6	450	82 .7%	630	77%	
1415	690	80	27	400	65	15.5	2.6	510	80 .4%	550	77%	
1445	720	82	28	400	65	16	2.5	560	78 .5%	480	82%	conc cond. 11,600
1515	750	83	28	400	65	16	2.5	600	76 .9%	500	82%	
1545	780	83	28	400	65	16	2.4	600	76 .9%	540	82%	
1615	810	83	28	400	65	16	2.4	590	77 .3%	570	81%	
1645	840	84	29	400	65	16.5	2.25	575	77 .9%	600	81%	conc cond. 10,400
1715	870	84	29	400	65	16.5	2.25	560	78 .5%	640	80%	

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Real Time	Elapsed Time (min)	Temp. (°F)	Temp. (°C)	Membrane PI (psig)	Filter Pressure (psig)	Conc. Rate (LPM)	Permeate Rate (LPM)	Cond. (µS/cm)	Rejection (%)	Tank Level (L)	Volume Reduction (%)	Comments
945	871	71	22	400	65	17	2.4	1130	56.5%	640	80%	RO conc. cond. 10500
1000	885	72	22	400	64	17	2.4	1030	60.4%	-	80%	
1015	900	73	23	400	64	17	2.25	930	64.2%	580	82%	
1030	915	74	23	400	64	17	2.1	900	65.4%	550	82%	
1045	930	75	24	400	64	17	2	900	65.4%	515	84%	
1115	960	78	26	400	64	17.5	1.8	1000	61.5%	460	86%	restart filling from MF
1145	990	80	27	400	64	17.5	1.8	1080	58.5%	500	85%	RO conc. cond. 13000
1215	1020	80	27	400	65	17.5	1.8	1150	55.8%	550	84%	
1245	1050	80	27	400	65	17.5	1.8	1175	54.8%	600	83%	
1300	1065	82	28	400	65	17.5	1.7	1150	55.8%	625	83%	no more feed input
1315	1080	82	28	400	65	17.5	1.7	1175	54.8%	600	83%	total feed = 3735
1345	1110	84	29	400	64	17.5	1.6	1125	56.7%	550	85%	
1415	1140	86	30	400	64	17.5	1.4	1075	58.7%	500	86%	RO conc. cond. 12500
1445	1170	88	31	400	64	18	1.2	975	62.5%	455	87%	
1515	1200	90	32	400	64	18	1	910	65.0%	420	88%	
1545	1230	92	33	400	64	18	0.8	930	64.2%	390	89%	
1600	1245	92	33	400	64	18	0.55	1000	61.5%	375	89%	start stability
1615	1260	93	34	400	64	19	0.48	1090	58.1%	375	89%	RO conc. cond. 14800
1630	1275	94	34	400	64	19	0.36	1200	53.8%	375	89%	
1645	1290	94	34	400	64	19	0.29	1320	49.2%	375	89%	
1700	1305	94	34	400	64	19	0.22	1500	42.3%	375	89%	
1715	1320	94	34	400	64	19	0.14	1770	31.9%	375	89%	RO conc. cond. 14700
1730	1335	94	34	400	64	19	0.1	2150	17.3%	375	89%	

Table D-5

Application : Leachate Treatment
System: Reverse Osmosis
Test No. 10

Type: **Stability at 80%**
Pretreatment : **None**

Date: **Nov 1,'89**

Real Time	Elapsed Time (min)	Temp. (°F)	Temp. (°C)	Membrane PI (psig)	Filter Pressure (psig)	Conc. Rate (LPM)	Permeate Rate (LPM)	Cond. (μS/cm)	Rejection (%)	Tank Level (L)	Volume Reduction (%)	Comments
1300	0	54	12	400	64	17	2.25	178	83 .0%	250	0 %	first 50 L rejected as rinse
1315	15	56	13	400	64	16.5	2.25	121	88 .5%	260	0 %	5μ cartridge filter replaced
1330	30	59	15	400	64	16	2.4	90	91 .4%	285	27 %	(old one had caked on white
1400	60	63	17	400	64	16	2.7	85	91 .9%	330	35 %	solids)
1430	90	66	19	400	64	15.5	3	80	92 .4%	355	42 %	conc cond. 1640
1500	120	68	20	400	64	15.5	3.25	79	92 .5%	370	48 %	conc cond. 2500
1600	180	71	22	400	63	15	3.5	166	84 .2%	175	74 %	conc cond. 4000
1630	210	73	23	400	64	15	3.1	140	86 .7%	180	76 %	
830	211	53	12	400	63	17	2.6	-	-	200	73 %	stability while filling
845	225	57	14	400	63	17	2.7	164	84 .4%	270	74 %	
900	240	59	15	400	63	16	2.8	125	88 .1%	320	65 %	restart conc., conc cond 3100
930	270	61	16	400	64	16	2.8	103	90 .2%	375	63 %	
1000	300	63	17	400	64	15.5	2.8	96	90 .9%	410	64 %	
1030	330	64	18	400	64	15.5	2.8	94	91 .0%	440	65 %	
1100	360	66	19	400	64	15.5	2.8	95	91 .0%	470	66 %	conc cond 3250
1130	390	67	19	400	64	15.5	2.8	95	91 .0%	490	67 %	
1200	420	67	19	400	64	16	2.8	97	90 .8%	500	68 %	
1230	450	71	22	400	64	15.5	2.8	118	88 .8%	410	68 %	
1300	480	73	23	400	64	16	2.8	136	87 .0%	370	77 %	
1330	510	72	22	400	64	16	2.6	131	87 .5%	380	77 %	
1400	540	72	22	400	64	16	2.6	130	87 .6%	400	78 %	conc cond 4300
1430	570	72	22	400	64	16	2.4	131	87 .5%	410	78 %	
1500	600	72	22	400	64	16	2.4	130	87 .6%	440	77 %	
1530	630	72	22	400	64	16	2.4	136	87 .0%	450	78 %	
1600	660	72	22	400	64	16	2.4	135	87 .1%	475	78 %	
1630	690	73	23	400	64	16.5	2.3	136	87 .0%	500	78 %	conc cond 4000
900	691	58	14	400	64	18	2.1	-	-	500	78 %	
915	705	60	16	400	64	18	2.1	275	72 .5%	-	78 %	conc cond. 4250 μS/cm
930	720	62	17	400	64	18	2	240	76 .0%	440	80 %	
1000	750	63	17	400	64	17.5	2	210	79 .0%	500	79 %	
1030	780	64	18	400	64	17.5	2	183	81 .7%	550	78 %	
1100	810	66	19	400	64	17	1.9	180	82 .0%	530	78 %	
1130	840	70	21	400	64	17	1.9	190	81 .0%	470	81 %	conc cond. 4500 μS/cm
1200	870	70	21	400	64	17.5	2	176	82 .4%	510	80 %	
1230	900	70	21	400	64	17.5	1.8	166	83 .4%	550	79 %	
1300	930	70	21	400	64	17.5	1.8	161	83 .9%	590	79 %	conc cond. 4250 μS/cm
1330	960	70	21	400	64	17	1.8	156	84 .4%	625	78 %	mf perm to drain
1415	975	73	23	400	64	17	1.8	163	83 .7%	545	81 %	

Real Time	Elapsed Time (min)	Temp. (°F)	Temp. (°C)	Membrane PI (psig)	Filter Pressure (psig)	Conc. Rate (LPM)	Permeate Rate (LPM)	Cond. (µS/cm)	Rejection (%)	Tank Level (L)	Volume Reduction (%)	Comments
1430	990	74	23	400	64	17	1.8	178	82 .2%	520	82 %	conc cond. 4750 µS/cm
1500	1020	74	23	400	64	17	1.8	181	81 .9%	550	81 %	
1530	1050	74	23	400	64	17	1.8	164	83 .6%	585	81 %	
1600	1080	74	23	400	64	17	1.8	171	82 .9%	620	80 %	
1630	1110	74	23	400	64	17	1.8	170	83 .0%	570	82 %	conc cond. 4250 µS/cm
915	1110	57	14	400	63	18.5	1.3	-	-	570	82 %	
930	1110	59	15	400	63	18.5	1.3	-	-	570	82 %	
945	1110	60	16	400	63	18.5	1.3	300	70 .0%	570	82 %	
1030	1125	64	18	400	63	18.5	1.3	275	72 .5%	570	82 %	
1100	1155	66	19	400	63	18	1.4	290	71 .0%	525	83 %	
1030	1185	69	21	400	63	18	1.4	300	70 .0%	490	84 %	conc 5100 µS/cm
1200	1215	69	21	400	63	18	1.4	275	72 .5%	540	83 %	
1230	1245	68	20	400	63	18	1.4	250	75 .0%	590	82 %	
1300	1275	68	20	400	63	18	1.3	230	77 .0%	640	81 %	
1330	1305	71	22	400	64	18	1.3	250	75 .0%	590	83 %	conc 4750 µS/cm
1400	1335	73	23	400	64	18	1.3	260	74 .0%	550	84 %	
1430	1365	75	24	400	64	18	1.3	280	72 .0%	510	85 %	
1500	1395	75	24	400	64	18	1.3	270	73 .0%	510	85 %	
1530	1425	76	24	400	64	18	1.3	260	74 .0%	510	85 %	
1600	1455	78	26	400	64	18	1.3	280	72 .0%	510	85 %	

Table D-6

Application : Leachate Treatment
System: Reverse Osmosis **Type: Concentration to 85%**
Test No. 11 **Pretreatment : 50% HCl to pH 6** **Date: Nov 8, '89**

Real Time	Elapsed Time (min)	Temp (°F)	Temp (°C)	Membrane PI (psig)	Filter Pressure (psig)	Concentrate		Permeate		Cond. (µS/cm)	Rejection (%)	Tank Level (L)	Volume Reduction (%)	Comments
						Rate (LPM)	pH	Rate (LPM)	pH					
1330	0	50	10	400	63	16	7.2	3	6.3	550	56.0%	175	0%	conc. 1450 µS/cm
1400	30	58	14	400	63	15.5	7.0	3.75	5.6	48	96.2%	275	0%	100 ml 50% HCl added
1430	60	62	17	400	63	14.5	7.3	4	6.3	43	96.6%	360	0%	50 ml 50% HCl added
1500	90	64	18	400	63	14	7.1	4.25	5.8	44	96.5%	460	0%	conc cond 1430/START CONC
1530	120	66	19	400	64	14	7.4	4.4	6.0	49	96.1%	455	16%	150 ml 50% HCl added
1600	150	67	19	400	64	14	6.8	4.4	5.5	70	94.4%	430	31%	
1630	180	68	20	400	64	14	7.0	4.4	5.6	75	94.0%	400	43%	conc cond. 2200
930	180	58	14	400	63	15	7.4	3.75	-	82	92.3%	400	43%	stability (both RO & MF)
1000	210	62	17	400	64	14	6.9	4	-	83	92.2%	440	43%	200 ml HCl
1030	240	66	19	400	64	14	6.5	4.4	5.3	92	91.3%	440	43%	conc 2800
1045	255	68	20	400	64	14	6.5	4.5	5.3	92	91.3%	440	41%	
1100	270	68	20	400	64	13.5	-	4.5	-	92	91.3%	440	45%	
1120	290	68	20	400	64	13.5	6.9	4.5	5.6	95	91.0%	420	52%	conc 3200 100 ml HCl
1200	300	73	23	400	63	13.5	6.6	4.75	5.4	108	89.8%	420	52%	conc 3300 100 ml HCl
1230	330	76	24	400	64	13	6.3	5	5.2	120	88.7%	420	52%	
1300	360	76	24	400	64	13	6.7	5	-	123	88.4%	390	60%	100 ml HCl
1330	390	75	24	400	63	13	6.6	4.75	5.5	143	86.5%	360	66%	conc 4400
1340	400	75	24	400	63	13.5	6.9	4.75	-	145	86.3%	350	68%	200 ml HCl
1400	420	74	23	400	64	13.5	6.2	4.5	5.1	175	83.5%	335	71%	conc 5100
1430	450	74	23	400	64	13.5	6.6	4.5	-	180	83.0%	310	75%	
1500	480	78	26	400	64	13.5	-	5	-	180	83.0%	310	75%	
1530	510	84	29	400	63	13	-	5.25	-	180	83.0%	310	75%	RO stability 200 ml HCl
1600	540	83	28	400	64	13	6.2	5.25	5.2	178	83.2%	390	71%	MF conc. cond 5250
1000	550	62	17	400	63	15	6.4	3.75	5.4	177	84.6%	410	70%	conc 4750
1030	580	64	18	400	64	14.5	6.8	4	5.8	143	87.6%	490	66%	200 ml HCl
1100	610	64	18	400	64	14.5	6.4	4	-	148	87.1%	530	66%	
1130	640	66	19	400	64	14.5	-	4	-	144	87.5%	530	68%	
1200	670	67	19	400	64	14.5	6.6	4.1	-	144	87.5%	530	68%	conc 4500 200 ml HCl
1230	700	69	21	400	64	14	5.9	4.25	5.0	164	85.7%	530	68%	conc 4700
1300	730	68	20	400	64	14.5	-	4	-	160	86.1%	530	70%	100 ml HCl
1330	760	68	20	400	64	14.5	6.5	4	-	162	85.9%	525	72%	
1400	790	68	20	400	64	14.5	6.4	4	5.3	173	85.0%	515	74%	conc 5300
1430	820	68	20	400	64	14	-	3.8	-	178	84.5%	500	76%	200 ml HCl
1500	850	68	20	400	64	14	6.3	3.8	5.3	195	83.0%	495	77%	conc 5500
1530	880	68	20	400	64	14.5	-	3.8	-	198	82.8%	485	79%	
1600	910	68	20	400	64	14.5	6.8	3.8	5.5	250	78.3%	475	80%	conc 6500

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Nov 8, '89

Real Time	Elapsed Time (min)	Temp (°F)	Temp (°C)	Membrane PI (psig)	Filter Pressure (psig)	Concentrate Rate (LPM)	Concentrate pH	Permeate Rate (LPM)	Permeate pH	Cond. (µS/cm)	Rejection (%)	Tank Level (L)	Volume Reduction (%)	Comments
830	915	52	11	400	64	16.5	6.9	2.5	5.9	240	79.1%	475	80%	stability 80 %
900	940	56	13	400	63	16.5	6.9	2.75	-	250	78.3%	475	80%	conc 6250
930	970	58	14	400	64	16	6.5	3	-	250	78.3%	475	80%	140 ml HCl
1000	1000	58	14	400	63	16	6.5	3	5.9	250	78.3%	475	80%	conc 6500
1030	1030	62	17	400	64	14.5	6.5	3.75	5.5	260	77.4%	475	80%	
1100	1060	66	19	400	64	14.5	6.5	3.75	5.5	260	77.4%	475	80%	
1130	1090	68	20	400	64	14	-	4	-	260	77.4%	475	80%	start conc to 85 %
1200	1120	68	20	400	64	14	6.8	4	-	260	77.4%	470	81%	200 ml HCl
1230	1150	68	20	400	64	14	6.4	3.8	-	-	-	460	82%	100 ml HCl
1300	1180	69	21	400	64	14	6.4	3.75	-	310	73.0%	405	84%	
1310	1190	69	21	400	64	14	6.4	3.75	-	330	71.3%	380	85%	
1330	1210	71	22	400	64	14	6.4	3.75	5.3	340	70.4%	-	85%	conc 8500
1400	1240	74	23	400	64	14	-	4	-	340	70.4%	-	85%	
1430	1270	75	24	400	64	14	6.5	4.25	-	340	70.4%	-	85%	conc 8500
1500	1300	76	24	400	64	14	-	4.25	-	340	70.4%	-	85%	total HCl added = 2340 ml

Table D-7

Application : Leachate Treatment
System: Reverse Osmosis
Test No. 12

Type: Stability at 0%, 50%, 75%, 90%
Pretreatment : 50% HCl to pH 6

Date: Nov 13, '89

Real Time	Elapsed Time (min)	Temp. (°F)	Temp. (°C)	Membrane PI (psig)	Filter Pressure (psig)	Conc. Rate (LPM)	Conc. pH	Permeate Rate (LPM)	Permeate pH	Cond. (µS/cm)	Rejection (%)	Tank Level (L)	Volume Reduction (%)	Comments
1300	0	50	10	400	63	16	6.8	2.8	-	65	95.4%	360	0%	conc 1675 300 ml HCl
1315	15	53	12	400	63	15.5	6.5	3	5.3	70	95.0%	400	0%	
1330	30	56	13	400	63	15	6.7	3.3	5.5	67	95.2%	470	0%	conc 1740 200 ml HCl
1400	60	59	15	400	63	15	6.4	3.5	-	83	94.1%	500	15%	
1430	90	61	16	400	64	14.5	6.7	3.75	-	87	93.8%	510	28%	conc 2600 200 ml HCl
1500	120	62	17	400	64	14		3.75	-	103	92.6%	515	36%	
900	120	61	16	400	64	14.5	6.5	3.8	5.5	107	90.4%	520	36%	conc 3000
930	150	65	18	400	64	14	6.5	4.25	-	104	90.7%	520	36%	200 ml HCl
1000	180	66	19	400	64	14	6.2	4.1	-	115	89.7%	530	41%	
1030	210	66	19	400	64	14	6.5	4	-	115	89.7%	540	47%	conc 3300 200 ml HCl
1100	240	66	19	400	64	14	6.3	4	5.2	125	88.8%	550	52%	conc 3600
1130	270	66	19	400	64	14	6.6	4	-	127	88.7%	560	55%	200 ml HCl
1200	300	66	19	400	64	14	6.4	4	-	138	87.7%	570	58%	conc 4200
1230	330	68	20	400	64	14	6.4	4	5.4	166	85.2%	450	67%	conc 5000 200 ml HCl
1300	360	70	21	400	64	14	6.2	4	-	185	83.5%	440	70%	
1330	390	70	21	400	64	14	6.6	4	-	186	83.4%	440	72%	conc 5500 200 ml HCl
1400	420	70	21	400	64	14	6.3	4	5.2	198	82.3%	450	73%	
1430	450	71	22	400	64	14	6.6	4	5.5	200	82.1%	450	75%	conc 6000, (perm 250 HACH)
1500	480	71	22	400	64	14	6.5	4	5.3	260	76.8%	450	76%	125 ml HCl (+ bottle rinse)
1530	510	72	22	400	64	14	6.7	4	5.5	300	73.2%	380	80%	conc 7100
900	510	55	13	400	64	16.5	6.9	2	-	-	-	380	80%	stability @ 80 % conc
930	540	61	16	400	64	15	-	3	-	310	72.3%	380	80%	conc cond 7000 µS/cm
1000	570	65	18	400	64	14	-	3.5	-	300	73.2%	380	80%	
1030	600	68	20	400	64	14	-	3.75	-	300	73.2%	380	80%	
1100	630	71	22	400	64	14	-	4	-	300	73.2%	380	80%	conc cond 7200 µS/cm
1130	660	74	23	400	64	13.5	-	4	-	300	73.2%	380	80%	
1200	690	76	24	400	64	13.5	-	4.3	-	300	73.2%	380	80%	
1230	720	78	26	400	64	13	-	4.5	-	300	73.2%	380	80%	conc cond 7300 µS/cm
1300	750	79	26	400	64	13	-	4.5	-	300	73.2%	380	80%	
1330	780	81	27	400	64	13	-	4.75	-	300	73.2%	380	80%	
1400	810	82	28	400	64	13	-	5	-	300	73.2%	380	80%	conc cond 7500 µS/cm
1430	840	83	28	400	64	13	-	5	-	300	73.2%	380	80%	
1500	870	84	29	400	64	13	-	5	-	300	73.2%	380	80%	
1530	900	85	29	400	64	13	-	5	-	300	73.2%	380	80%	conc cond 7500 µS/cm
1400	930	86	30	400	64	13	6.9	5	-	300	73.2%	380	80%	

Appendix E

Analytical Data

Table E-1: Raw Analytical Data for Microfiltration Test #3

Component	MDL	Raw Leachate	Treated Feed	50% MF Concentrate	50% MF Permeate	75% MF Concentrate	75% MF Permeate	90% MF Concentrate	90% MF Permeate
TOC	1	200	-	-	-	-	-	310	900
COD	10	470	-	-	-	-	-	470	440
BOD5		-	-	-	-	-	-	-	-
TDS	10	550	-	-	-	-	-	1500	1400
TSS	10	26	-	-	-	-	-	5400	<
Fluoride	0.1	<	-	9.2	9.2	9.2	-	<	<
Chloride	0.2	25	-	21	23	20	-	23	22
Nitrate (as N)	0.2	<	-	<	<	<	-	<	<
Bromide	0.8	<	-	<	<	<	-	<	<
Phosphate (as P)	0.8	<	-	<	<	<	-	<	<
Sulphate	1	1.3	-	1.6	1.7	1.7	-	1.6	1.6
Calcium	0.023	74	-	520	2	930	-	2600	1.2
Magnesium	0.05	9.9	-	230	40	380	-	880	52
Sodium	0.1	14	-	450	430	460	-	440	430
Potassium	0.5	24	-	23	22	23	-	23	23
Aluminum	0.03	0.1	-	0.19	<	0.38	-	1	<
Barium	0.001	0.25	-	0.41	<	0.74	-	1.8	0.003
Beryllium	0.001	<	-	<	<	<	-	<	<
Boron	0.01	0.21	-	0.21	0.18	0.24	-	0.32	0.16
Cadmium	0.002	<	-	<	<	0.003	-	<	<
Chromium	0.004	0.004	-	0.01	<	0.023	-	0.047	<
Cobalt	0.01	0.02	-	0.03	<	0.06	-	0.13	<
Copper	0.006	<	-	<	<	<	-	0.007	0.014
Iron	0.01	140	-	220	0.05	380	-	880	0.08
Lead	0.02	<	-	0.046	<	0.07	-	0.15	0.029
Manganese	0.005	2.4	-	3.9	<	7	-	17	<
Molybdenum	0.02	<	-	<	<	<	-	<	<
Nickel	0.01	<	-	<	<	<	-	<	<
Phosphorus	0.06	0.08	-	0.22	0.13	0.21	-	0.26	0.08
Silicon	0.05	9	-	12	0.18	21	-	49	0.53
Silver	0.01	<	-	<	<	<	-	0.019	<
Strontium	0.001	0.46	-	0.84	0.01	1.5	-	3.6	0.008
Sulphur	0.06	1.6	-	5.4	1.2	8.5	-	18	1.2
Thalium	0.06	<	-	<	<	<	-	<	<
Titanium	0.01	<	-	0.04	<	0.05	-	0.09	<
Vanadium	0.005	0.005	-	<	<	0.008	-	0.023	<
Zinc	0.005	0.015	-	0.05	<	0.09	-	0.24	<
Zirconium	0.01	<	-	<	<	0.014	-	0.033	<

MDL - minimum detection limit
< - less than MDL

Table E-2: Raw Analytical Data for Reverse Osmosis Test #5

Component	MDL	Raw Leachate	Ro Feed	25% RO Concentrate	25% RO Permeate	50% RO Concentrate	50% RO Permeate	75% RO Concentrate	75% RO Permeate	90% RO Concentrate	90% RO Permeate
TOC	1	230	360	-	-	-	-	-	-	2000	3
COD	10	410	570	-	-	-	-	-	-	6000	<
BOD5		-	-	-	-	-	-	-	-	-	-
TDS	10	-	-	-	-	-	-	-	-	-	-
TSS	10	12	<	-	-	-	-	-	-	<	<
Fluoride	0.1	<	<	<	<	<	<	<	<	<	0.22
Chloride	0.2	30	32	45	<	68	<	110	<	220	1.5
Nitrate (as N)	0.2	<	<	<	<	<	<	<	<	2	<
Bromide	0.8	<	<	<	<	<	<	<	<	<	<
Phosphate (as P)	0.8	<	<	<	<	<	<	<	<	<	<
Sulphate	1	1.7	2.4	2.8	<	3.6	<	9.4	<	16	<
Calcium	0.023	86	2.1	2.7	0.1	3.9	0.12	6.4	0.05	8.3	2.8
Magnesium	0.05	14	91	120	0.07	180	0.05	300	<	430	0.52
Sodium	0.1	16	660	880	11	1300	11	2200	14	3200	28
Potassium	0.5	22	32	43	0.07	62	0.7	100	1	150	2.4
Aluminum	0.03	0.04	<	<	<	<	<	<	<	<	0.1
Barium	0.001	0.270	0.003	0.003	0.002	0.006	<	0.013	<	0.011	0.004
Beryllium	0.001	<	<	<	<	<	<	<	<	<	<
Boron	0.01	0.21	0.26	0.35	<	0.52	<	0.87	0.01	1.3	0.05
Cadmium	0.002	<	<	<	<	<	<	<	<	<	<
Chromium	0.004	<	<	<	<	<	<	<	<	<	0.005
Cobalt	0.01	0.03	<	<	<	<	<	<	<	<	<
Copper	0.006	<	<	<	<	<	<	<	<	0.007	0.006
Iron	0.01	150	<	<	<	<	<	<	<	<	0.13
Lead	0.02	0.03	<	<	0.026	<	<	<	<	<	<
Manganese	0.005	2.5	<	<	<	<	<	<	<	<	0.02
Molybdenum	0.02	<	<	<	<	<	<	<	<	<	<
Nickel	0.01	<	<	<	<	<	<	<	<	<	<
Phosphorus	0.06	0.42	0.17	0.21	<	0.35	<	0.65	<	0.85	<
Silicon	0.05	8.9	1.7	2.2	<	0.32	<	0.52	<	7.6	0.36
Silver	0.01	<	<	<	<	<	<	<	<	<	<
Strontium	0.001	0.490	0.011	0.014	<	0.022	<	0.037	<	0.047	0.005
Sulphur	0.06	1.7	2	0.278	0.11	3.8	<	5.9	0.11	8.5	0.23
Thalium	0.06	<	<	<	0.14	<	<	<	<	<	<
Titanium	0.01	0.03	<	<	<	<	<	<	<	<	<
Vanadium	0.005	<	<	<	<	<	<	<	<	0.005	0.006
Zinc	0.005	0.020	0.014	<	0.01	<	<	0.008	<	0.006	0.018
Zirconium	0.01	<	<	<	<	<	<	<	<	<	<
Cond. Rejection					94%		94%		93%		90%

MDL - minimum detection limit
< - less than MDL

Table E-3: Raw Analytical Data for Test #6/7

Component	MDL	Raw Leachate	Treated Feed	90% MF Concentrate	90% MF Permeate	47% MF Concentrate	47% MF Permeate	1st 94% RO Concentrate	1st 94% RO Permeate
pH (@ 20 °c)		-	-	-	-	-	-	-	-
Alkalinity		-	-	-	-	-	-	-	-
TOC	1	-	-	-	-	-	-	-	-
COD	10	-	-	-	-	-	-	-	-
BOD5		-	-	-	-	-	-	-	-
TDS	10	-	-	-	-	-	-	-	-
TSS	10	-	-	-	-	-	-	-	-
Fluoride	0.1	-	-	-	-	-	-	-	-
Chloride	0.2	-	-	-	-	-	-	-	-
Nitrate (as N)	0.2	-	-	-	-	-	-	-	-
Bromide	0.8	-	-	-	-	-	-	-	-
Phosphate (as P)	0.8	-	-	-	-	-	-	-	-
Sulphate	1	-	-	-	-	-	-	-	-
Calcium	0.023	63	300	380	2.7	2100	1.9	29	0.39
Magnesium	0.05	8.9	150	180	19	880	48	610	0.15
Sodium	0.1	12	420	420	400	440	430	7200	27
Potassium	0.5	17	18	17	17	19	18	300	1.2
Aluminum	0.03	0.4	0.12	0.15	<	0.88	<	<	<
Barium	0.001	0.28	0.27	0.33	<	1.7	<	0.012	<
Beryllium	0.001	<	<	<	<	<	<	<	<
Boron	0.01	0.18	0.18	0.17	0.17	0.26	0.16	2.6	0.1
Cadmium	0.002	0.002	0.003	<	<	<	<	<	<
Chromium	0.004	<	0.008	0.009	<	0.032	<	<	<
Cobalt	0.01	0.014	0.02	0.02	<	0.1	<	<	<
Copper	0.006	<	<	<	<	0.012	<	0.017	<
Iron	0.01	120	120	140	0.07	730	0.11	0.06	0.06
Lead	0.02	<	0.032	<	<	0.12	<	<	<
Manganese	0.005	<	2	2.4	<	13	<	<	<
Molybdenum	0.02	<	<	<	<	<	<	<	<
Nickel	0.01	<	<	<	<	<	<	0.034	<
Phosphorus	0.06	0.11	0.07	0.08	<	0.21	<	0.5	<
Silicon	0.05	7.2	7.5	8.5	2.9	39	0.11	36	0.11
Silver	0.01	<	<	<	<	<	<	<	<
Strontium	0.001	0.4	0.45	0.54	0.017	2.8	0.088	0.17	<
Sulphur	0.06	1.3	3.6	4.1	1.1	16	1.3	19	<
Thalium	0.06	<	0.067	<	<	0.075	<	0.082	<
Titanium	0.01	0.017	0.021	0.023	0.013	0.066	0.013	0.016	0.013
Vanadium	0.005	0.01	0.013	0.016	<	0.088	<	0.013	<
Zinc	0.005	0.024	0.044	0.056	0.007	0.29	0.007	0.015	0.008
Zirconium	0.01	<	<	<	<	0.027	<	<	<

MDL - minimum detection limit
< - less than MDL

Table E-3: Raw Analytical Data for Test #6/7

Component	MDL	Treated Feed	94% MF Concentrate	94% MF Permeate	2nd 94% RO Concentrate	2nd 94% RO Permeate
pH (@ 20 °c)		-	-	-	-	-
Alkalinity		-	-	-	-	-
TOC	1	-	-	-	-	-
COD	10	-	-	-	-	-
BOD5		-	-	-	-	-
TDS	10	-	-	-	-	-
TSS	10	-	-	-	-	-
Fluoride	0.1	-	-	-	-	-
Chloride	0.2	-	-	-	-	-
Nitrate (as N)	0.2	-	-	-	-	-
Bromide	0.8	-	-	-	-	-
Phosphate (as P)	0.8	-	-	-	-	-
Sulphate	1	-	-	-	-	-
Calcium	0.023	520	4200	1.5	20	0.45
Magnesium	0.05	240	1700	67	260	2.3
Sodium	0.1	440	470	430	6900	140
Potassium	0.5	19	20	19	290	5.9
Aluminum	0.03	0.23	1.8	<	<	<
Barium	0.001	0.47	3.3	<	0.009	<
Beryllium	0.001	<	<	<	<	<
Boron	0.01	0.2	0.38	0.16	2.4	0.35
Cadmium	0.002	<	<	<	<	<
Chromium	0.004	0.012	0.057	<	0.005	<
Cobalt	0.01	0.04	0.2	<	<	<
Copper	0.006	<	0.014	<	0.012	<
Iron	0.01	220	1700	0.04	0.03	0.02
Lead	0.02	0.03	0.22	<	<	<
Manganese	0.005	3.5	25	<	<	<
Molybdenum	0.02	<	<	<	<	<
Nickel	0.01	<	<	<	0.028	<
Phosphorus	0.06	0.1	0.38	<	0.53	0.08
Silicon	0.05	12	80	0.76	27	0.53
Silver	0.01	<	<	<	<	<
Strontium	0.001	0.77	5.2	0.008	0.15	<
Sulphur	0.06	5.2	27	1.2	18	0.24
Thalium	0.06	<	0.18	<	0.083	<
Titanium	0.01	0.029	0.12	0.012	0.016	0.011
Vanadium	0.005	0.025	0.21	<	0.011	<
Zinc	0.005	0.076	0.55	0.008	<	<
Zirconium	0.01	<	0.058	<	<	<

MDL - minimum detection limit
< - less than MDL

Table E-4: Raw Analytical Data for Microfiltration Test #8

Component	MDL	Treated Feed	50% MF Concentrate	50% MF Permeate	67% MF Concentrate	67% MF Permeate	50% MF Concentrate	76% MF Concentrate	76% MF Permeate	61% MF Concentrate	96% MF Concentrate	96% MF Permeate
TOC	1	230	250	250	460	220	230	230	230	270	260	400
COD	10	-	-	-	-	-	-	-	-	-	460	480
BOD5		-	-	-	-	-	-	-	-	-	-	-
TDS	10	1400	1500	1400	1500	1500	1200	1200	1400	1200	820	1300
TSS	10	1600	2300	<	4500	<	3000	6300	<	3500	33000	-
Fluoride	0.1	-	-	-	-	-	-	-	-	-	<	<
Chloride	0.2	-	-	-	-	-	-	-	-	-	32	32
Nitrate (as N)	0.2	-	-	-	-	-	-	-	-	-	<	<
Bromide	0.8	-	-	-	-	-	-	-	-	-	<	<
Phosphate (as P)	0.8	-	-	-	-	-	-	-	-	-	<	<
Sulphate	1	-	-	-	-	-	-	-	-	-	2.3	2.3
Calcium	0.023	-	-	-	-	-	-	-	-	-	6400	0.97
Magnesium	0.05	-	-	-	-	-	-	-	-	-	2600	37
Sodium	0.1	-	-	-	-	-	-	-	-	-	550	490
Potassium	0.5	-	-	-	-	-	-	-	-	-	20	21
Aluminum	0.03	-	-	-	-	-	-	-	-	-	2.4	<
Barium	0.001	-	-	-	-	-	-	-	-	-	4.4	<
Beryllium	0.001	-	-	-	-	-	-	-	-	-	<	<
Boron	0.01	-	-	-	-	-	-	-	-	-	0.61	0.16
Cadmium	0.002	-	-	-	-	-	-	-	-	-	0.008	<
Chromium	0.004	-	-	-	-	-	-	-	-	-	0.085	<
Cobalt	0.01	-	-	-	-	-	-	-	-	-	0.29	<
Copper	0.006	-	-	-	-	-	-	-	-	-	<	<
Iron	0.01	160	220	0.03	410	1.2	270	570	0.75	340	3500	0.04
Lead	0.02	-	-	-	-	-	-	-	-	-	0.32	<
Manganese	0.005	-	-	-	-	-	-	-	-	-	34	<
Molybdenum	0.02	-	-	-	-	-	-	-	-	-	<	<
Nickel	0.01	-	-	-	-	-	-	-	-	-	<	<
Phosphorus	0.06	-	-	-	-	-	-	-	-	-	0.46	0.1
Silicon	0.05	-	-	-	-	-	-	-	-	-	180	0.7
Silver	0.01	-	-	-	-	-	-	-	-	-	<	<
Strontium	0.001	-	-	-	-	-	-	-	-	-	7.4	<
Sulphur	0.06	-	-	-	-	-	-	-	-	-	36	1.1
Thalium	0.06	-	-	-	-	-	-	-	-	-	0.12	<
Titanium	0.01	-	-	-	-	-	-	-	-	-	0.15	<
Vanadium	0.005	-	-	-	-	-	-	-	-	-	0.24	<
Zinc	0.005	-	-	-	-	-	-	-	-	-	0.57	<
Zirconium	0.01	-	-	-	-	-	-	-	-	-	0.09	<
Hardness (as CaCO3)	1	1400	2000	150	3600	220	2400	840	190	3000	-	-

MDL - minimum detection limit
< - less than MDL

Table E-5: Raw Analytical Data for Reverse Osmosis Test #8

Component	MDL	Raw Leachate	71% RO Concentrate	71% RO Permeate	77% RO Concentrate	77% RO Permeate	89% RO Concentrate	89% RO Permeate
TOC	1	170	1100	7	1100	30	1600	120
COD	10	490	-	-	-	-	3500	140
BOD5		-	-	-	-	-	-	-
TDS	10	650	6100	44	7300	210	12000	540
TSS	10	48	<	<	<	<	18	<
Fluoride	0.1	<	-	-	-	-	0.19	<
Chloride	0.2	2.9	-	-	-	-	350	20
Nitrate (as N)	0.2	<	-	-	-	-	0.5	0.25
Bromide	0.8	<	-	-	-	-	<	<
Phosphate (as P)	0.8	<	-	-	-	-	<	<
Sulphate	1	<	-	-	-	-	17	<
Calcium	0.023	72	-	-	-	-	7.2	0.61
Magnesium	0.05	12	-	-	-	-	250	8.2
Sodium	0.1	13	-	-	-	-	4000	190
Potassium	0.5	20	-	-	-	-	160	8.4
Aluminum	0.03	0.046	-	-	-	-	<	<
Barium	0.001	0.28	-	-	-	-	0.009	<
Beryllium	0.001	<	-	-	-	-	<	<
Boron	0.01	0.2	-	-	-	-	1.2	0.13
Cadmium	0.002	<	-	-	-	-	<	<
Chromium	0.004	<	-	-	-	-	<	<
Cobalt	0.01	0.2	-	-	-	-	<	<
Copper	0.006	<	-	-	-	-	<	<
Iron	0.01	150	0.04	0.01	0.04	0.04	0.08	0.21
Lead	0.02	<	-	-	-	-	<	<
Manganese	0.005	2.1	-	-	-	-	<	<
Molybdenum	0.02	<	-	-	-	-	<	<
Nickel	0.01	<	-	-	-	-	<	<
Phosphorus	0.06	0.06	-	-	-	-	0.24	<
Silicon	0.05	9	-	-	-	-	10	0.5
Silver	0.01	<	-	-	-	-	<	<
Strontium	0.001	0.43	-	-	-	-	0.034	0.002
Sulphur	0.06	1.4	-	-	-	-	8.9	0.45
Thalium	0.06	<	-	-	-	-	<	<
Titanium	0.01	0.012	-	-	-	-	<	<
Vanadium	0.005	0.009	-	-	-	-	<	<
Zinc	0.005	0.013	-	-	-	-	<	<
Zirconium	0.01	<	-	-	-	-	<	<
Hardness(as CaCO3)	1		830	1	5100	19	-	-
Cond. Rejection				94%		83%		55%

MDL - minimum detection limit
< - less than MDL

Table E-6: Raw Analytical Data for Test #10

Component	MDL	Raw Leachate	82% MF Concentrate	82% MF Permeate	85% RO Concentrate	85% RO Permeate
TOC	1	190	190	250	1500	58
COD	10	430	420	420	2700	90
BOD5		-	-	-	-	-
TDS	10	580	550	600	3700	180
TSS	10	120	1700	<	<	<
Fluoride	0.1	<	<	<	<	<
Chloride	0.2	20	21	21	95	9.5
Nitrate (as N)	0.2	<	<	<	0.04	<
Bromide	0.8	<	<	<	<	<
Phosphate (as P)	0.8	<	<	<	<	<
Sulphate	1	<	<	<	<	<
Calcium	0.023	73	540	20	57	1.8
Magnesium	0.05	11	140	100	600	19
Sodium	0.1	15	14	15	93	6.2
Potassium	0.5	23	23	24	130	12
Aluminum	0.03	0.13	0.51	<	<	<
Barium	0.001	0.26	0.78	0.007	0.008	<
Beryllium	0.001	<	<	<	<	<
Boron	0.01	0.21	0.23	0.17	0.68	0.16
Cadmium	0.002	<	<	<	<	<
Chromium	0.004	0.004	0.02	<	<	<
Cobalt	0.01	0.02	0.07	<	<	<
Copper	0.006	<	<	<	0.007	<
Iron	0.01	130	460	<	0.02	<
Lead	0.02	0.025	0.084	<	<	<
Manganese	0.005	2.4	7.7	<	0.26	0.008
Molybdenum	0.02	<	<	<	<	<
Nickel	0.01	<	<	<	0.02	<
Phosphorus	0.06	0.1	0.16	<	0.31	<
Silicon	0.05	8.6	24	1.1	17	0.71
Silver	0.01	<	<	<	<	<
Strontium	0.001	0.47	1.1	1.3	0.18	0.005
Sulphur	0.06	1.6	5.7	0.068	7.3	0.26
Thalium	0.06	<	0.11	<	0.2	<
Titanium	0.01	0.019	0.04	<	<	<
Vanadium	0.005	0.011	0.047	<	<	<
Zinc	0.005	0.014	0.091	<	0.006	<
Zirconium	0.01	<	0.02	<	<	<
Cond. Rejection						75%

MDL - minimum detection limit

< - less than MDL

Table E-6: Raw Analytical Data for Test #10

Microfiltration

Component	MDL	Treated Feed	32% Concentrate	48% Concentrate	48% Permeate	58% Concentrate	65% Concentrate	65% Permeate	74% Concentrate	74% Permeate
TOC	1	240	290	250	230	190	230	230	230	240
COD	10	-	-	-	-	-	-	-	-	-
BOD5		-	-	-	-	-	-	-	-	-
TDS	10	460	640	490	650	530	630	540	600	630
TSS	10	650	670	1200	<	930	1200	<	800	<
Iron	0.01	130	190	250	<	280	370	<	400	<
Hardness (as CaCO3)	1	850	1100	1200	440	1300	1600	430	1700	450

Reverse Osmosis

Component	MDL	48% Concentrate	48% Permeate	68% Concentrate	68% Permeate	78% Concentrate	78% Permeate
TOC	1	440	14	890	16	1100	30
COD	10	-	-	-	-	-	-
BOD5		-	-	-	-	-	-
TDS	10	1200	40	2000	60	2900	110
TSS	10	<	<	<	<	<	<
Iron	0.01	<	<	<	<	0.1	<
Hardness (as CaCO3)	1	1100	18	1500	21	1900	49
Cond. Rejection			93 %		91 %		82 %

MDL - minimum detection limit
< - less than MDL

Table E-7: Raw Analytical Data for Test #11

Component (mg/L)	MDL	Raw Leachate	Treated Feed	MF * Concentrate	MF * Permeate	RO * Concentrate	RO * Permeate
pH (@ 20 °c)		5.98	9.12	9.29	7.87	7.06	5.79
Alkalinity		180	1200	1800	360	740	30
TOC	1	150	180	180	170	750	9
COD	10	430	470	470	450	2000	29
BOD5		220	210	217	235	1330	15
TDS	10	490	550	580	650	2900	100
TSS	10	240	1200	1700	<	<	<
Fluoride	0.1	<	<	<	<	<	<
Chloride	0.2	20	20	21	21	910	28
Nitrate (as N)	0.2	<	<	<	<	<	<
Bromide	0.8	<	<	<	<	<	<
Phosphate (as P)	0.8	<	<	<	<	<	<
Sulphate	1	1.4	2.3	2.2	2.2	9.3	<
Calcium	0.023	70	270	440	50	290	5.9
Magnesium	0.05	10	120	150	72	300	5.5
Sodium	0.1	13	14	14	14	60	2.3
Potassium	0.5	21	22	21	22	92	4.7
Aluminum	0.03	0.088	0.19	0.34	<	<	<
Barium	0.001	0.24	0.3	0.51	0.029	0.19	0.004
Beryllium	0.001	0.001	<	<	<	<	<
Boron	0.01	0.21	0.22	0.22	0.19	0.6	0.11
Cadmium	0.002	<	<	<	<	0.002	<
Chromium	0.004	0.005	0.011	0.018	<	0.006	<
Cobalt	0.01	0.02	0.03	0.05	<	<	<
Copper	0.006	<	<	<	<	0.011	<
Iron	0.01	130	190	330	0.87	1.7	0.02
Lead	0.02	<	<	0.053	<	<	<
Manganese	0.005	2.2	3	5.3	0.08	0.56	0.011
Molybdenum	0.02	<	<	<	<	<	<
Nickel	0.01	<	<	<	<	0.04	<
Phosphorus	0.06	<	0.09	0.1	<	0.21	<
Silicon	0.05	8.2	11	17	2.8	13	0.35
Silver	0.01	<	<	<	<	<	<
Strontium	0.001	0.44	0.55	0.82	0.2	1.1	0.021
Sulphur	0.06	1.6	3.4	5.1	3.4	8.1	0.77
Thalium	0.06	<	<	0.067	<	0.09	<
Titanium	0.01	0.017	0.024	0.034	<	<	<
Vanadium	0.005	0.006	0.015	0.023	<	<	<
Zinc	0.005	0.013	0.032	0.068	<	0.03	0.005
Zirconium	0.01	<	<	0.012	<	<	<

MDL - minimum detection limit
< - less than MDL
* - composite sample

Table E-8: Raw Analytical Data for Reverse Osmosis Test #11

Component (mg/L)	MDL	50% RO Concentrate	50% RO Permeate	66% RO Concentrate	66% RO Permeate	75% RO Concentrate	75% RO Permeate	80% RO Concentrate	80% RO Concentrate
pH (@ 20 °c)		6.56	5.25	6.82	5.51	6.69	5.5	6.85	5.69
Alkalinity		-	-	-	-	-	-	-	-
TOC	1	450	9	660	14	790	16	970	18
COD	10	-	-	-	-	-	-	-	-
BOD5		780	17	-	-	-	-	1700	23
Cond. Rejection			91 %		87 %		83 %		77 %

MDL - minimum detection limit
< - less than MDL

Table E-9: Raw Analytical Data for Test #12

Component (mg/L)	MDL	Raw Leachate	Treated Feed	MF * Concentrate	MF * Permeate	RO * Concentrate	RO * Permeate
pH (@ 20 °c)		5.96	8.82	9.16	7.42	6.89	5.79
Alkalinity		180	950	1500	430	670	20
TOC	1	158	170	170	200	600	11
COD	10	430	470	440	440	1500	43
BOD5		-	-	257	245	936	14
TDS	10	530	630	690	600	2660	130
TSS	10	230	1200	1600	<	3	<
Fluoride	0.1	<	<	<	<	<	<
Chloride	0.2	21	22	22	22	800	35
Nitrate (as N)	0.2	<	<	<	<	<	<
Bromide	0.8	<	<	<	<	<	<
Phosphate (as P)	0.8	<	<	<	<	<	<
Sulphate	1	1.8	2.2	2.3	2.3	7.4	<
Calcium	0.023	72	230	430	69	350	8.9
Magnesium	0.05	10	100	140	72	240	5.7
Sodium	0.1	14	14	14	15	50	2.2
Potassium	0.5	22	22	22	23	77	3.7
Aluminum	0.03	0.078	0.17	0.34	0.05	0.03	<
Barium	0.001	0.24	0.25	0.55	0.055	0.26	0.008
Beryllium	0.001	0.001	<	<	<	<	<
Boron	0.01	0.23	0.22	0.24	0.2	0.54	0.07
Cadmium	0.002	<	<	<	<	<	<
Chromium	0.004	0.005	0.011	0.019	<	<	<
Cobalt	0.01	0.02	0.02	0.6	<	<	<
Copper	0.006	<	<	<	<	0.008	<
Iron	0.01	130	170	400	3	1.2	0.02
Lead	0.02	<	<	0.051	<	<	<
Manganese	0.005	2.3	2.6	6	0.19	1.2	0.03
Molybdenum	0.02	<	<	<	<	<	<
Nickel	0.01	<	<	<	<	0.02	<
Phosphorus	0.06	<	0.07	0.09	0.06	0.18	<
Silicon	0.05	8.3	9.7	18	3.5	13	0.35
Silver	0.01	<	<	<	<	0.026	<
Strontium	0.001	0.45	0.49	0.81	0.25	1.1	0.027
Sulphur	0.06	1.5	3.3	4.9	2.2	6.8	0.38
Thalium	0.06	<	<	<	<	0.07	<
Titanium	0.01	0.016	0.023	0.033	<	<	<
Vanadium	0.005	0.005	0.008	0.024	<	<	<
Zinc	0.005	0.009	0.038	0.065	0.018	0.021	<
Zirconium	0.01	<	<	0.013	<	<	<

MDL - minimum detection limit
< - less than MDL
* - composite sample

Table E-10: Raw Analytical Data for Reverse Osmosis Test #12

Component (mg/L)	MDL	50% RO Concentrate	50% RO Permeate	66% RO Concentrate	66% RO Permeate	75% RO Concentrate	75% RO Permeate	80% RO Concentrate	80% RO Permeate
pH (@ 20 °c)		6.44	5.28	6.49	5.33	6.77	5.51	6.84	5.54
Alkalinity		470	20	-	-	-	-	970	40
TOC	1	440	10	640	15	790	20	960	20
COD	10	1000	29	-	-	-	-	2500	50
BOD5		644	12	-	-	-	-	1750	26
TDS	10	1900	40	-	-	-	-	2800	110
TSS	10	<	<	-	-	-	-	5	<
Fluoride	0.1	<	<	-	-	-	-	<	<
Chloride	0.2	560	23	-	-	-	-	1500	58
Nitrate (as N)	0.2	<	<	-	-	-	-	<	<
Bromide	0.8	<	<	-	-	-	-	<	<
Phosphate (as P)	0.8	<	<	-	-	-	-	<	<
Sulphate	1	5.3	<	-	-	-	-	<	<
Calcium	0.023	290	8.2	-	-	-	-	460	11
Magnesium	0.05	150	4	-	-	-	-	440	9.6
Sodium	0.1	35	1.4	-	-	-	-	81	3
Potassium	0.5	55	2.7	-	-	-	-	120	6.5
Aluminum	0.03	<	<	-	-	-	-	<	<
Barium	0.001	0.21	0.01	-	-	-	-	0.33	0.009
Beryllium	0.001	<	<	-	-	-	-	<	<
Boron	0.01	0.41	0.07	-	-	-	-	0.73	0.15
Cadmium	0.002	<	<	-	-	-	-	<	<
Chromium	0.004	<	<	-	-	-	-	<	<
Cobalt	0.01	<	<	-	-	-	-	<	<
Copper	0.006	<	<	-	-	-	-	<	<
Iron	0.01	0.85	0.02	-	-	-	-	0.64	<
Lead	0.02	<	<	-	-	-	-	<	<
Manganese	0.005	1	0.03	-	-	-	-	1.4	0.032
Molybdenum	0.02	<	<	-	-	-	-	<	<
Nickel	0.01	<	<	-	-	-	-	0.038	<
Phosphorus	0.06	0.15	<	-	-	-	-	0.27	<
Silicon	0.05	10	0.27	-	-	-	-	19	0.51
Silver	0.01	<	<	-	-	-	-	0.033	<
Strontium	0.001	0.85	0.024	-	-	-	-	1.6	0.037
Sulphur	0.06	5.3	0.37	-	-	-	-	10	0.42
Thalium	0.06	0.08	<	-	-	-	-	0.13	<
Titanium	0.01	<	<	-	-	-	-	<	<
Vanadium	0.005	<	<	-	-	-	-	<	<
Zinc	0.005	0.011	<	-	-	-	-	0.015	<
Zirconium	0.01	<	<	-	-	-	-	<	<
Cond. Rejection			89 %		85 %		82 %		73 %

MDL - minimum detection limit

< - less than MDL

Table E-11: Process Rejections for Test #3

Component	MDL	Raw Leachate	Treated Feed	MF Permeate *	% MF Rejection	RO Permeate *	% RO Rejection	Total Process Rejection
TOC (mg/L)	1	200	-	900	-	-	-	-
COD	10	470	-	440	6.4%	-	-	-
BOD5		-	-	-	-	-	-	-
TDS (mg/L)	10	550	-	1400	-	-	-	-
TSS	10	26	-	<	>61.5%	-	-	-
Fluoride (mg/L)	0.1	<	-	9.2	-	-	-	-
Chloride	0.2	25	-	22.5	10.0%	-	-	-
Nitrate (as N)	0.2	<	-	<	-	-	-	-
Bromide	0.8	<	-	<	-	-	-	-
Phosphate (as P)	0.8	<	-	<	-	-	-	-
Sulphate	1	1.3	-	1.65	-	-	-	-
Calcium (mg/L)	0.023	75	-	1.6	97.9%	-	-	-
Magnesium	0.05	9.9	-	46	-	-	-	-
Sodium	0.1	14	-	430	-	-	-	-
Potassium	0.5	24	-	22.5	6.3%	-	-	-
Aluminum	0.03	0.1	-	<	>70.0%	-	-	-
Barium	0.001	0.25	-	0.003	98.8%	-	-	-
Beryllium	0.001	<	-	<	-	-	-	-
Boron	0.01	0.21	-	0.17	19.0%	-	-	-
Cadmium	0.002	<	-	<	-	-	-	-
Chromium	0.004	0.004	-	<	>0.0%	-	-	-
Cobalt	0.01	0.02	-	<	>50.0%	-	-	-
Copper	0.006	<	-	0.014	-	-	-	-
Iron	0.01	140	-	0.065	>99.9%	-	-	-
Lead	0.02	<	-	0.029	-	-	-	-
Manganese	0.005	2.4	-	<	>99.8%	-	-	-
Molybdenum	0.02	<	-	<	-	-	-	-
Nickel	0.01	<	-	<	-	-	-	-
Phosphorus	0.06	0.08	-	0.105	-	-	-	-
Silicon	0.05	9	-	0.355	96.1%	-	-	-
Silver	0.01	<	-	<	-	-	-	-
Strontium	0.001	0.46	-	0.009	98.0%	-	-	-
Sulphur	0.06	1.6	-	1.2	25.0%	-	-	-
Thalium	0.06	<	-	<	-	-	-	-
Titanium	0.01	<	-	<	-	-	-	-
Vanadium	0.005	0.005	-	<	>0.0%	-	-	-
Zinc	0.005	0.015	-	<	>66.7%	-	-	-
Zirconium	0.01	<	-	<	-	-	-	-
Hardness (as CaCO3)	1	-	-	-	-	-	-	-
Cond. Rejection		-	-	-	-	-	-	-

MDL - minimum detection limit

< - less than MDL

* - average of permeate samples taken

Table E-12: Process Rejections for Test #5

Component	MDL	Raw Leachate	Treated Feed	MF Permeate	% MF Rejection	RO Permeate *	% RO Rejection	Total Process Rejection
TOC (mg/L)	1	230	-	360	-	3.00	99.2%	98.7%
COD	10	410	-	570	-	<	>98.2%	>97.6%
BOD5		-	-	-	-	-	-	-
TDS (mg/L)	10	-	-	-	-	-	-	-
TSS	10	12	-	<	>16.7%	<	-	>16.7%
Fluoride (mg/L)	0.1	<	-	<	-	0.22	-	-
Chloride	0.2	30	-	32	-	1.50	95.3%	95.0%
Nitrate (as N)	0.2	<	-	<	-	<	-	-
Bromide	0.8	<	-	<	-	<	-	-
Phosphate (as P)	0.8	<	-	<	-	<	-	-
Sulphate	1	1.7	-	2.4	-	<	>58.3%	>41.2%
Calcium (mg/L)	0.023	86	-	2.1	97.6%	0.77	63.5%	99.1%
Magnesium	0.05	14	-	91	-	0.21	99.8%	98.5%
Sodium	0.1	16	-	660	-	16	97.6%	0.0%
Potassium	0.5	22	-	32	-	1.04	96.7%	95.3%
Aluminum	0.03	0.04	-	<	>25.0%	0.10	-	-
Barium	0.001	0.27	-	0.003	98.9%	0.00	0.0%	98.9%
Beryllium	0.001	<	-	<	-	<	-	-
Boron	0.01	0.21	-	0.26	-	0.03	88.5%	85.7%
Cadmium	0.002	<	-	<	-	<	-	-
Chromium	0.004	<	-	<	-	0.005	-	-
Cobalt	0.01	0.03	-	<	>66.7%	<	-	>66.7%
Copper	0.006	<	-	<	-	0.006	-	-
Iron	0.01	150	-	<	>99.9%	0.13	-	99.9%
Lead	0.02	0.03	-	<	>33.3%	0.026	-	13.3%
Manganese	0.005	2.5	-	<	>99.8%	0.02	-	99.2%
Molybdenum	0.02	<	-	<	-	<	-	-
Nickel	0.01	<	-	<	-	<	-	-
Phosphorus	0.06	0.42	-	0.17	59.5%	<	-	>85.7%
Silicon	0.05	8.9	-	1.7	80.9%	0.36	78.8%	96.0%
Silver	0.01	<	-	<	-	<	-	-
Strontium	0.001	0.49	-	0.011	97.8%	0.005	54.5%	99.0%
Sulphur	0.06	1.7	-	2	-	0.17	91.5%	90.0%
Thalium	0.06	<	-	<	-	0.14	-	-
Titanium	0.01	0.03	-	<	>66.7%	<	-	>66.7%
Vanadium	0.005	<	-	<	-	0.006	-	-
Zinc	0.005	0.02	-	0.014	30.0%	0.01	0.0%	30.0%
Zirconium	0.01	<	-	<	-	<	-	-
Hardness (as CaCO3)	1	-	-	-	-	-	-	-
Cond. Rejection		-	-	-	-	-	93%	-

MDL - minimum detection limit

< - less than MDL

* - average of permeate samples taken

Table E-13: Process Rejections for Test #6/7

Component	MDL	Raw Leachate	Treated Feed	MF Permeate *	% MF Rejection	RO Permeate *	% RO Rejection	Total Process Rejection
TOC (mg/L)	1	-	-	-	-	-	-	-
COD	10	-	-	-	-	-	-	-
BOD5		-	-	-	-	-	-	-
TDS (mg/L)	10	-	-	-	-	-	-	-
TSS	10	-	-	-	-	-	-	-
Fluoride (mg/L)	0.1	-	-	-	-	-	-	-
Chloride	0.2	-	-	-	-	-	-	-
Nitrate (as N)	0.2	-	-	-	-	-	-	-
Bromide	0.8	-	-	-	-	-	-	-
Phosphate (as P)	0.8	-	-	-	-	-	-	-
Sulphate	1	-	-	-	-	-	-	-
Calcium (mg/L)	0.023	63	300	20	93.3%	1.8	91.0%	97.1%
Magnesium	0.05	8.9	150	100	33.3%	19	81.0%	-
Sodium	0.1	12	420	15	96.4%	6.2	58.7%	48.3%
Potassium	0.5	17	18	24	-	12	50.0%	29.4%
Aluminum	0.03	0.4	0.12	<	>75.0%	<	-	>92.5%
Barium	0.001	0.28	0.27	0.007	97.4%	<	>85.7%	>99.6%
Beryllium	0.001	<	<	<	-	<	-	-
Boron	0.01	0.18	0.18	0.17	5.6%	0.16	5.9%	11.1%
Cadmium	0.002	0.002	0.003	<	>33.3%	<	-	-
Chromium	0.004	<	0.008	<	>50.0%	<	-	-
Cobalt	0.01	0.014	0.02	<	>50.0%	<	-	>28.6%
Copper	0.006	<	<	<	-	<	-	-
Iron	0.01	120	120	<	>99.9%	<	-	>99.9%
Lead	0.02	<	0.032	<	>37.5%	<	-	-
Manganese	0.005	<	2	<	>99.8%	0.008	-	-
Molybdenum	0.02	<	<	<	-	<	-	-
Nickel	0.01	<	<	<	-	<	-	-
Phosphorus	0.06	0.11	0.07	<	>14.3%	<	-	>45.5%
Silicon	0.05	7.2	7.5	1.1	85.3%	0.71	35.5%	90.1%
Silver	0.01	<	<	<	-	<	-	-
Strontium	0.001	0.4	0.45	1.3	-	0.005	99.6%	98.8%
Sulphur	0.06	1.3	3.6	0.068	98.1%	0.26	-	80.0%
Thalium	0.06	<	0.067	<	>10.4%	<	-	-
Titanium	0.01	0.017	0.021	<	>52.4%	<	-	>41.2%
Vanadium	0.005	0.01	0.013	<	>61.5%	<	-	>50.0%
Zinc	0.005	0.024	0.044	<	>88.6%	<	-	>79.2%
Zirconium	0.01	<	<	<	-	<	-	-
Hardness (as CaCO3)	1	-	-	-	-	-	-	-
Cond. Rejection		-	-	-	-	-	94%	-

MDL - minimum detection limit

< - less than MDL

* - average of permeate samples taken

Table E-14: Process Rejections for Test #8

Component	MDL	Raw Leachate	Treated Feed	MF Permeate *	% MF Rejection	RO Pemeate *	% RO Rejection	Total Process Rejection
TOC (mg/L)	1	190	230	275	-	52	81.0%	77.2%
COD	10	490	-	480	2.0%	140	70.8%	71.4%
BOD5		-	-	-	-	-	-	-
TDS (mg/L)	10	650	1400	1400	0.0%	265	81.1%	59.3%
TSS	10	48	1600	<	>99.4%	<	-	>99.4%
Fluoride (mg/L)	0.1	<	-	<	-	<	-	-
Chloride	0.2	2.9	-	32	-	20	37.5%	-
Nitrate (as N)	0.2	<	-	<	-	0.25	-	-
Bromide	0.8	<	-	<	-	<	-	-
Phosphate (as P)	0.8	<	-	<	-	<	-	-
Sulphate	1	<	-	2.3	-	<	>56.5%	-
Calcium (mg/L)	0.023	72	-	0.97	98.7%	0.61	37.1%	99.2%
Magnesium	0.05	12	-	37	-	8.2	77.8%	31.7%
Sodium	0.1	13	-	490	-	190	61.2%	-
Potassium	0.5	20	-	21	-	8.4	60.0%	58.0%
Aluminum	0.03	0.046	-	<	>34.8%	<	-	>34.8%
Barium	0.001	0.28	-	<	>99.6%	<	-	>99.6%
Beryllium	0.001	<	-	<	-	<	-	-
Boron	0.01	0.2	-	0.16	20.0%	0.13	18.8%	35.0%
Cadmium	0.002	<	-	<	-	<	-	-
Chromium	0.004	<	-	<	-	<	-	-
Cobalt	0.01	0.2	-	<	>95.0%	<	-	>95.0%
Copper	0.006	<	-	<	-	<	-	-
Iron	0.01	150	160	0.51	99.7%	0.09	82.8%	99.9%
Lead	0.02	<	-	<	-	<	-	-
Manganese	0.005	2.1	-	<	>99.8%	0.008	-	99.6%
Molybdenum	0.02	<	-	<	-	<	-	-
Nickel	0.01	<	-	<	-	<	-	-
Phosphorus	0.06	0.06	-	0.1	-	<	>40.0%	>0.0%
Silicon	0.05	9	-	0.7	92.2%	0.5	28.6%	94.4%
Silver	0.01	<	-	<	-	<	-	-
Strontium	0.001	0.43	-	<	>99.8%	0.002	-	99.5%
Sulphur	0.06	1.4	-	1.1	21.4%	0.45	59.1%	67.9%
Thalium	0.06	<	-	<	-	<	-	-
Titanium	0.01	0.012	-	<	>16.7%	<	-	>16.7%
Vanadium	0.005	0.009	-	<	>44.4%	<	-	>44.4%
Zinc	0.005	0.013	-	<	>61.5%	<	-	>61.5%
Zirconium	0.01	<	-	<	-	<	-	-
Hardness (as CaCO3)		-	1400	187	86.7%	10	94.6%	99.3%
Cond. Rejection		-	-	-	-	-	77%	-

MDL - minimum detectio limit
< - less than MDL
* - average of permeate samples taken

Table E-15: Process Rejections for Test #10

Component	MDL	Raw Leachate	Treated Feed	MF Permeate *	% MF Rejection	RO Permeate *	% RO Rejection	Total Process Rejection
TOC (mg/L)	1	190	240	238	0.8%	30	87.4%	87.5%
COD	10	430	-	420	2.3%	90	78.6%	79.1%
BOD5		-	-	-	-	-	-	-
TDS (mg/L)	10	580	460	605	-	98	83.8%	78.7%
TSS	10	120	650	<	>98.5%	<	-	>98.5%
Fluoride (mg/L)	0.1	<	-	<	-	<	-	-
Chloride	0.2	20	-	21	-	9.5	54.8%	-
Nitrate (as N)	0.2	<	-	<	-	<	-	-
Bromide	0.8	<	-	<	-	<	-	-
Phosphate (as P)	0.8	<	-	<	-	<	-	-
Sulphate	1	<	-	<	-	<	-	-
Calcium (mg/L)	0.023	73	-	20	72.6%	1.8	91.0%	97.5%
Magnesium	0.05	11	-	100	-	19	81.0%	-
Sodium	0.1	15	-	15	0.0%	6.2	58.7%	58.7%
Potassium	0.5	23	-	24	-	12	50.0%	47.8%
Aluminum	0.03	0.13	-	<	>76.9%	<	-	>76.9%
Barium	0.001	0.26	-	0.007	97.3%	<	>85.7%	>99.6%
Beryllium	0.001	<	-	<	-	<	-	-
Boron	0.01	0.21	-	0.17	19.0%	0.16	5.9%	23.8%
Cadmium	0.002	<	-	<	-	<	-	-
Chromium	0.004	0.004	-	<	>0.0%	<	-	>0.0%
Cobalt	0.01	0.02	-	<	>50.0%	<	-	>50.0%
Copper	0.006	<	-	<	-	<	-	-
Iron	0.01	130	130	<	>99.9%	<	-	>99.9%
Lead	0.02	0.025	-	<	>20.0%	<	-	>20.0%
Manganese	0.005	2.4	-	<	>99.8%	0.008	-	99.7%
Molybdenum	0.02	<	-	<	-	<	-	-
Nickel	0.01	<	-	<	-	<	-	-
Phosphorus	0.06	0.1	-	<	>40.0%	<	-	>40.0%
Silicon	0.05	8.6	-	1.1	87.2%	0.71	35.5%	91.7%
Silver	0.01	<	-	<	-	<	-	-
Strontium	0.001	0.47	-	1.3	-	0.005	99.6%	98.9%
Sulphur	0.06	1.6	-	0.068	95.8%	0.26	-	83.8%
Thalium	0.06	<	-	<	-	<	-	-
Titanium	0.01	0.019	-	<	>47.4%	<	-	>47.4%
Vanadium	0.005	0.011	-	<	>54.5%	<	-	>54.5%
Zinc	0.005	0.014	-	<	>64.3%	<	-	>64.3%
Zirconium	0.01	<	-	<	-	<	-	-
Hardness (as CaCO3)	1	-	850	440	48.2%	29	93.4%	96.6%
Cond. Rejection		-	-	-	-	-	85.0%	-

MDL - minimum detection limit

< - less than MDL

* - average of permeate samples taken

Table E-16: Process Rejections for Test #11

Component	MDL	Raw Leachate	Treated Feed	MF Permeate	% MF Rejection	RO Permeate	% RO Rejection	Total Process Rejection
pH (@ 20 °c)		5.98	9.12	7.87	-	5.79	-	-
Alkalinity (mg/L)		180	1200	360	70.0%	30	91.7%	97.5%
TOC (mg/L)	1	150	180	170	5.6%	9	94.7%	95.0%
COD	10	430	470	450	4.3%	29	93.6%	93.8%
BOD5		220	210	235	-	15	93.6%	92.9%
TDS (mg/L)	10	490	550	650	-	100	84.6%	81.8%
TSS	10	240	1200	<	>99.2%	<	-	>99.2%
Fluoride (mg/L)	0.1	<	<	<	-	<	-	-
Chloride	0.2	20	20	21	-	28	-33.3%	-
Nitrate (as N)	0.2	<	<	<	-	<	-	-
Bromide	0.8	<	<	<	-	<	-	-
Phosphate (as P)	0.8	<	<	<	-	<	-	-
Sulphate	1	1.4	2.3	2.2	4.3%	<	>54.5%	>56.5%
Calcium (mg/L)	0.023	70	270	50	81.5%	5.9	88.2%	97.8%
Magnesium	0.05	10	120	72	40.0%	5.5	92.4%	95.4%
Sodium	0.1	13	14	14	0.0%	2.3	83.6%	83.6%
Potassium	0.5	21	22	22	0.0%	4.7	78.6%	78.6%
Aluminum	0.03	0.088	0.19	<	>84.2%	<	-	>84.2%
Barium	0.001	0.24	0.3	0.029	90.3%	0.004	86.2%	98.7%
Beryllium	0.001	0.001	<	<	-	<	-	-
Boron	0.01	0.21	0.22	0.19	13.6%	0.11	42.1%	50.0%
Cadmium	0.002	<	<	<	-	<	-	-
Chromium	0.004	0.005	0.011	<	>63.6%	<	-	>63.6%
Cobalt	0.01	0.02	0.03	<	>66.7%	<	-	>66.7%
Copper	0.006	<	<	<	-	<	-	-
Iron	0.01	130	190	0.87	99.5%	0.02	97.7%	100.0%
Lead	0.02	<	<	<	-	<	-	-
Manganese	0.005	2.2	3	0.08	97.3%	0.011	86.3%	99.6%
Molybdenum	0.02	<	<	<	-	<	-	-
Nickel	0.01	<	<	<	-	<	-	-
Phosphorus	0.06	<	0.09	<	>33.3%	<	-	>33.3%
Silicon	0.05	8.2	11	2.8	74.5%	0.35	87.5%	96.8%
Silver	0.01	<	<	<	-	<	-	-
Strontium	0.001	0.44	0.55	0.2	63.6%	0.021	89.5%	96.2%
Sulphur	0.06	1.6	3.4	3.4	0.0%	0.77	77.4%	77.4%
Thalium	0.06	<	<	<	-	<	-	-
Titanium	0.01	0.017	0.024	<	>58.3%	<	-	>58.3%
Vanadium	0.005	0.006	0.015	<	>66.7%	<	-	>66.7%
Zinc	0.005	0.013	0.032	<	>84.4%	0.005	-	84.4%
Zirconium	0.01	<	<	<	-	<	-	-
Hardness (as CaCO3)		-	-	-	-	-	-	-
Cond. Rejection		-	-	-	-	-	90.0%	-

MDL - minimum detection limit

< - less than MDL

Table E-17: Process Rejections for Test #12

Component	MDL	Raw Leachate	Treated Feed	MF Permeate	% MF Rejection	RO Permeate	% RO Rejection	Total Process Rejection
pH (@ 20 °c)		5.96	8.82	7.42	-	5.79	-	-
Alkalinity (mg/L)		180	950	430	54.7%	20	95.3%	97.9%
TOC (mg/L)	1	158	170	200	-	11	94.5%	93.5%
COD	10	430	470	440	6.4%	43	90.2%	90.9%
BOD5		-	-	245	-	14	94.3%	-
TDS	10	530	630	600	4.8%	130	78.3%	79.4%
TSS	10	230	1200	<	>99.2%	<	-	>99.2%
Fluoride (mg/L)	0.1	<	<	<	-	<	-	-
Chloride	0.2	21	22	22	0.0%	35	-	-
Nitrate (as N)	0.2	<	<	<	-	<	-	-
Bromide	0.8	<	<	<	-	<	-	-
Phosphate (as P)	0.8	<	<	<	-	<	-	-
Sulphate	1	1.8	2.2	2.3	-	<	>56.5%	-
Calcium (mg/L)	0.023	72	230	69	70.0%	8.9	87.1%	96.1%
Magnesium	0.05	10	100	72	28.0%	5.7	92.1%	94.3%
Sodium	0.1	14	14	15	-	2.2	85.3%	84.3%
Potassium	0.5	22	22	23	-	3.7	83.9%	83.2%
Aluminum	0.03	0.078	0.17	0.05	70.6%	<	>40.0%	>82.4%
Barium	0.001	0.24	0.25	0.055	78.0%	0.008	85.5%	96.8%
Beryllium	0.001	0.001	<	<	-	<	-	
Boron	0.01	0.23	0.22	0.2	9.1%	0.07	65.0%	68.2%
Cadmium	0.002	<	<	<	-	<	-	-
Chromium	0.004	0.005	0.011	<	>63.6%	<	-	>63.6%
Cobalt	0.01	0.02	0.02	<	>50.0%	<	-	>50.0%
Copper	0.006	<	<	<	-	<	-	
Iron	0.01	130	170	3	98.2%	0.02	99.3%	>99.9%
Lead	0.02	<	<	<	-	<	-	-
Manganese	0.005	2.3	2.6	0.19	92.7%	0.03	84.2%	98.8%
Molybdenum	0.02	<	<	<	-	<	-	-
Nickel	0.01	<	<	<	-	<	-	-
Phosphorus	0.06	<	0.07	0.06	14.3%	<	>0.0%	>14.3%
Silicon	0.05	8.3	9.7	3.5	63.9%	0.35	90.0%	96.4%
Silver	0.01	<	<	<	-	<	-	-
Strontium	0.001	0.45	0.49	0.25	49.0%	0.027	89.2%	94.5%
Sulphur	0.06	1.5	3.3	2.2	33.3%	0.38	82.7%	88.5%
Thalium	0.06	<	<	<	-	<	-	-
Titanium	0.01	0.016	0.023	<	>56.5%	<	-	>56.5%
Vanadium	0.005	0.005	0.008	<	>37.5%	<	-	>37.5%
Zinc	0.005	0.009	0.038	0.018	52.6%	<	-	>86.8%
Zirconium	0.01	<	<	<	-	<	-	-
EPA624 ($\mu g/L$)								
trans-1,2-Dichloroethane	1.1	3.8	-	2	47.4%	1.4	30.0%	63.2%
1,1-Dichloroethane	0.5	4.8	-	2.2	54.2%	0.5	77.3%	89.6%
1,2-Dichloroethane	0.4	1.7	-	1.3	23.5%	0.9	30.8%	47.1%
Benzene	0.2	6.9	-	2.9	58.0%	0.8	72.4%	88.4%
Trichloroethane	0.3	2.4	-	1.1	54.2%	1.5	-	37.5%
Toluene	0.3	120	-	72	40.0%	14	80.6%	88.3%
Tetrachloroethene	0.2	1.1	-	0.8	27.3%	0.49	38.8%	55.5%
Ethylbenzene	0.3	22	-	11	50.0%	2.8	74.5%	87.3%
EPA-625 ($\mu g/L$)								
Phenol	1.1	300	-	66	78.0%	91	-	69.7%
Naphthalene	0.3	<	-	99	-	24	75.8%	-
Acenaphthene	0.7	32	-	88	-	24	72.7%	25.0%
Fluorene	0.3	24	-	46	-	6.1	86.7%	74.6%
Phenanthrene	0.3	14	-	24	-	7.8	67.5%	44.3%

MDL - minimum detection limit

< - less than MDL

Table E - 18a

INPUT DATA FOR SCALE CALCULATIONS

	TEST #5	CONC.	
Concentration		4	
Temperature (C)	20		
pH	10	10	
Electrical Conductance (uS/cm)			
TDS (mg/l)	0	0	
Silica (as SiO2)(mg/l)	3.638	14.552	Silicon x 2.14
Aluminum (mg/l)	0.03	0.12	
Barium	0.003	0.012	
Cadmium	0.002	0.008	
Calcium	2.1	8.4	
Iron	0.01	0.04	
Magnesium	91	364	
Manganese	0.005	0.02	
Potassium	32	128	
Sodium	660	2640	
Strontium	0.011	0.044	
Zinc	0.014	0.056	
Alkalinity (as CaCO3	1810	7240	
Bromide (mg/l)	0.8	3.2	
Chloride	32	128	
Fluoride	0.1	0.4	
Nitrate (as N)	0.2	0.8	
Nitrite (as N)	0.2	0.8	
Phosphate (as P)	0.8	3.2	
Sulfate	2.4	9.6	

Sum of Cations	**149.52**		
Sum of Anions	**-148.98**		
Charge Balance(%)	**0%**		
LANGELIER SATURATION INDEX		**3.37**	'+' = CaCO3 fouling potential
SATURATION pH = 6.63			'-' = no CaCO3 fouling
lb HCl/1000 gal to adjust =	**15.31**		
RELATIVE SATURATIONS	CaSO4 =	**0.00**	
	BaSO4 =	**0.01**	> 1 suggests scale formation potential
	SrSO4 =	**0.00**	
RELATIVE SILICA SATURATION		**0.05**	
OSMOTIC PRESSURE		**42**	psi

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Table E - 18b

INPUT DATA FOR SCALE CALCULATIONS

	TEST #8	CONC.	
Concentration		4	
Temperature (C)	20		
pH	10	10	
Electrical Conductance (uS/cm)			
TDS (mg/l)	1400	5600	
Silica (as SiO2)(mg/l)	1.498	5.992	Silicon x 2.14
Aluminum (mg/l)	0.03	0.12	
Barium	0.001	0.004	
Cadmium	0.002	0.008	
Calcium	0.97	3.88	
Iron	0.51	2.04	
Magnesium	37	148	
Manganese	0.005	0.02	
Potassium	21	84	
Sodium	490	1960	
Strontium	0.001	0.004	
Zinc	0.005	0.02	
Alkalinity (as CaCO3	1200	4800	
Bromide (mg/l)	0.8	3.2	
Chloride	32	128	
Fluoride	0.1	0.4	
Nitrate (as N)	0.2	0.8	
Nitrite (as N)	0.2	0.8	
Phosphate (as P)	0.8	3.2	
Sulfate	2.3	9.2	

Sum of Cations	**100.54**		
Sum of Anions	**-100.21**		
Charge Balance(%)	**0%**		
LANGELIER SATURATION INDEX		**2.36**	'+' = CaCO3 fouling potential
SATURATION pH = 7.64			'-' = no CaCO3 fouling
lb HCl/1000 gal to adjust =	**1.45**		
RELATIVE SATURATIONS	CaSO4 =	**0.00**	
	BaSO4 =	**0.01**	> 1 suggests scale formation potential
	SrSO4 =	**0.00**	
RELATIVE SILICA SATURATION		**0.02**	
OSMOTIC PRESSURE		**30**	psi

Table E - 18c

INPUT DATA FOR SCALE CALCULATIONS

	TEST #10	CONC.	
Concentration		4	
Temperature (C)	20		
pH	8	8	
Electrical Conductance (uS/cm)			
TDS (mg/l)	605	2420	
Silica (as SiO2)(mg/l)	2.354	9.416	Silicon x 2.14
Aluminum (mg/l)	0.03	0.12	
Barium	0.007	0.028	
Cadmium	0.002	0.008	
Calcium	20	80	
Iron	0.01	0.04	
Magnesium	100	400	
Manganese	0.005	0.02	
Potassium	24	96	
Sodium	15	60	
Strontium	1.3	5.2	
Zinc	0.005	0.02	
Alkalinity (as CaCO3)	500	2000	
Bromide (mg/l)	0.8	3.2	
Chloride	21	84	
Fluoride	0.1	0.4	
Nitrate (as N)	0.2	0.8	
Nitrite (as N)	0.2	0.8	
Phosphate (as P)	0.8	3.2	
Sulfate	1	4	

Sum of Cations	**42.84**		
Sum of Anions	**-42.91**		
Charge Balance(%)	**0%**		
LANGELIER SATURATION INDEX		**1.42**	'+' = CaCO3 fouling potential
SATURATION pH = 6.58			'-' = no CaCO3 fouling
lb HCl/1000 gal to adjust =	**4.38**		
RELATIVE SATURATIONS	CaSO4 =	**0.00**	
	BaSO4 =	**0.02**	> 1 suggests scale formation potential
	SrSO4 =	**0.00**	
RELATIVE SILICA SATURATION		**0.10**	
OSMOTIC PRESSURE		**8**	**psi**

Table E - 18d

INPUT DATA FOR SCALE CALCULATIONS

	TEST #11	CONC.	
Concentration		4	
Temperature (C)	20		
pH	6.5	6.5	
Electrical Conductance (uS/cm)			
TDS (mg/l)	650	2600	
Silica (as SiO2)(mg/l)	5.992	23.968	Silicon x 2.14
Aluminum (mg/l)	0.03	0.12	
Barium	0.029	0.116	
Cadmium	0.002	0.008	
Calcium	50	200	
Iron	0.87	3.48	
Magnesium	72	288	
Manganese	0.08	0.32	
Potassium	22	88	
Sodium	14	56	
Strontium	0.2	0.8	
Zinc	0.005	0.02	
Alkalinity (as CaCO3	360	1440	
Bromide (mg/l)	0.8	3.2	
Chloride	21	84	
Fluoride	0.1	0.4	
Nitrate (as N)	0.2	0.8	
Nitrite (as N)	0.2	0.8	
Phosphate (as P)	0.8	3.2	
Sulfate	2.2	8.8	

Sum of Cations	**39.20**		
Sum of Anions	**-31.82**		
Charge Balance(%)	**19%**		
LANGELIER SATURATION INDEX		**0.17**	'+' = CaCO3 fouling potential
SATURATION pH = 6.33			'-' = no CaCO3 fouling
lb HCl/1000 gal to adjust =	**1.43**		
RELATIVE SATURATIONS	CaSO4 =	**0.00**	
	BaSO4 =	**0.19**	> 1 suggests scale formation potential
	SrSO4 =	**0.00**	
RELATIVE SILICA SATURATION		**0.28**	
OSMOTIC PRESSURE		**8**	psi

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Table E - 18e

INPUT DATA FOR SCALE CALCULATIONS

	TEST #12	CONC.	
Concentration		4	
Temperature (C)	20		
pH	6.5	6.5	
Electrical Conductance (uS/cm)			
TDS (mg/l)	600	2400	
Silica (as SiO_2)(mg/l)	7.49	29.96	Silicon x 2.14
Aluminum (mg/l)	0.05	0.2	
Barium	0.055	0.22	
Cadmium	0.002	0.008	
Calcium	69	276	
Iron	3	12	
Magnesium	72	288	
Manganese	0.19	0.76	
Potassium	23	92	
Sodium	15	60	
Strontium	0.25	1	
Zinc	0.018	0.072	
Alkalinity (as $CaCO_3$	430	1720	
Bromide (mg/l)	0.8	3.2	
Chloride	22	88	
Fluoride	0.1	0.4	
Nitrate (as N)	0.2	0.8	
Nitrite (as N)	0.2	0.8	
Phosphate (as P)	0.8	3.2	
Sulfate	2.3	9.2	

Sum of Cations	**43.64**		
Sum of Anions	**-37.53**		
Charge Balance(%)	**14%**		
LANGELIER SATURATION INDEX		**0.39**	'+' = $CaCO_3$ fouling potential
SATURATION pH = 6.11			'-' = no $CaCO_3$ fouling
lb HCl/1000 gal to adjust =	**4.00**		
RELATIVE SATURATIONS	$CaSO_4$ =	**0.00**	
	$BaSO_4$ =	**0.36**	> 1 suggests scale formation potential
	$SrSO_4$ =	**0.00**	
RELATIVE SILICA SATURATION		**0.35**	
OSMOTIC PRESSURE		**8**	psi

Appendix F

System Design Specifications

TABLE F-1

Design Specifications for Precipitation / Microfiltration

Capacity (liters/day)	55,000	110,000	165,000
Capacity (US gpm)	10	20	30

Chemical Reaction System

System to Include: 1) Reaction Tank, 2) Mixer, 3) Chemical Storage Tanks, 4) Chemical Metering System and 5) pH probe, level switches and controls.

Lime Dosage (g/L)	0.5	0.5	0.5
Lime Required (kg/yr)	10,038	20,075	30,113
Reaction Tank Size (usgal)	150	300	450
Tank Retention Time (min)	15	15	15
Chemical Reaction System Cost ($)	$18,000	$23,000	$26,000

Microfiltration System

System to include: 1) Process Pump, 2) Membrane Modules, 3) CIP Tank, 4) interconnecting piping and 5) Meters and Controls

System Recovery	95%	95%	95%
Productive Operating Time	85%	85%	85%
Permeate Required (gpd)	16,094	32,188	48,282
Assumed Flux (gfd)	75	75	75
Membrane Area (sq. ft.)	215	429	644
Pump HP	20	40	50
MF System Cost ($)	$66,250	$115,100	$169,300

Filter Press

Includes semi automatic plate and frame filter press with controls.

Filter Cost ($)	$27,900	$34,400	$48,000

TABLE F-2

Capital and Operating Costs for Precipitation / Microfiltration

Capacity (liters/day)	55,000	110,000	165,000
Capacity (US gpm)	10	20	30
CAPITAL COSTS ($)			
Chemical Reaction System	$18,000	$23,000	$26,000
MF System	$66,250	$115,100	$169,300
Filter Press	$27,900	$34,400	$48,000
Total Equipment Costs	$112,150	$172,500	$243,300
Installation Costs	$123,365	$189,750	$267,630
TOTAL CAPITAL COST	$235,515	$362,250	$510,930
OPERATING COSTS ($/yr)			
Precipitation Chemicals Lime at $0.1/kg	$1,004	$2,008	$3,011
MF Membrane Replacement Membrane Life of 3 yr.	$7,153	$14,306	$21,459
MF System Power HPx0.746x24x365x$0.06/KW	$7,839	$15,678	$19,597
Labour 1 / 1.5 / 1.75 hr. /day @ $45 /hr	$16,425	$24,638	$28,744
Maintenance	$5,608	$8,625	$12,165
YEARLY OPERATING COSTS	$38,028	$65,253	$84,976
TOTAL COSTS ($/yr)			
Amortized Capital Costs (10 yr @11%)	$40,038	$61,583	$86,858
Operating Costs ($/yr)	$38,028	$65,253	$84,976
TOTAL YEARLY COSTS	$78,066	$126,836	$171,834
Cost per 1,000 liters	$3.89	$3.16	$2.85

TABLE F-3

Design Specifications for Precipitation / Clarification

Capacity (liters/day)	55,000	110,000	165,000
Capacity (US gpm)	10	20	30

Chemical Reaction System

System to Include: 1) Reaction Tank, 2) Mixer, 3) Chemical Storage Tanks, 4) Chemical Metering System and 5) pH probe, level switches and controls.

Lime Dosage (g/L)	0.5	0.5	0.5
Lime Required (kg/yr)	10,038	20,075	30,113
Polymer Dosage (mg/L)	2.0	2.0	2.0
Polymer Required (kg/yr)	40	80	120
Reaction Tank Size (usgal)	150	300	450
Tank Retention Time (min)	15	15	15
Chemical Reaction System Cost ($)	$22,000	$25,000	$28,000

Clarifier

System to include: 1) Transfer Pump, 2) Clarifier 3) interconnecting piping and 4) Meters and Controls

Flow Required (gpm)	10	20	30
Clarifier Cost ($)	$10,780	$12,450	$14,375

Sand Filter

Includes sand filter with controls.

Flow Required (gpm)	10	20	30
Filter Cost ($)	$7,800	$8,900	$10,600

Filter Press

Includes semi automatic plate and frame filter press with controls.

Filter Cost ($)	$27,900	$34,400	$48,000

TABLE F-4

Capital and Operating Costs for Precipitation / Clarification

Capacity (liters/day) Capacity (US gpm)	55,000 10	110,000 20	165,000 30
CAPITAL COSTS ($)			
Chemical Reaction System	$22,000	$25,000	$28,000
Clarifier	$10,780	$12,450	$14,375
Sand Filter	$7,800	$8,900	$10,600
Filter Press	$27,900	$34,400	$48,000
Total Equipment Costs	$68,480	$80,750	$100,975
Installation Costs	$75,328	$88,825	$111,073
TOTAL CAPITAL COST	$143,808	$169,575	$212,048
OPERATING COSTS ($/yr)			
Precipitation Chemicals			
Lime at $0.1/kg	$1,004	$2,008	$3,011
Polymer	$240	$486	$720
Labour 1.5 / 2 / 2.5 hr. /day @ $45 /hr	$24,638	$32,850	$41,063
Maintenance	$3,424	$4,038	$5,049
YEARLY OPERATING COSTS	$29,305	$39,381	$49,843
TOTAL COSTS ($/yr)			
Amortized Capital Costs (10 yr @11%)	$24,447	$28,828	$36,048
Operating Costs ($/yr)	$29,305	$39,381	$49,843
TOTAL YEARLY COSTS	$53,753	$68,209	$85,891
Cost per 1,000 liters	$2.68	$1.70	$1.43

TABLE F-5

Design Specifications for Reverse Osmosis

Capacity (liters/day)	55,000	110,000	165,000
Capacity (US gpm)	10	20	30
RO System			
System to include: 1) Process Pump, 2) Membrane Modules, 3) CIP Tank, 4) interconnecting piping and 5) Meters and Controls			
System Recovery	75%	75%	75%
Productive Operating Time	85%	85%	85%
Permeate Required (gpd)	12,706	25,412	38,118
Assumed Flux (gfd)	19	19	19
Membrane Area (sq. ft.)	669	1,337	2,006
Number of Membranes	8	17	25
Pump HP	10	18	25
RO System Cost ($)	$38,850	$58,420	$73,610

TABLE F-6

Capital and Operating Costs for Reverse Osmosis

Capacity (liters/day)	55,000	110,000	165,000
Capacity (US gpm)	10	20	30
CAPITAL COSTS ($)			
Reverse Osmosis System	$38,850	$58,420	$73,610
Total Equipment Costs	$38,850	$58,420	$73,610
Installation Costs	$42,735	$64,262	$80,971
TOTAL CAPITAL COST	$81,585	$122,682	$154,581
OPERATING COSTS ($/yr)			
RO Membrane Replacement Membrane Life of 2 yr.	$3,344	$6,687	$10,031
RO System Power HPx0.746x24x365x$0.06/KW	$3,919	$7,055	$9,798
Labour 1 / 1.5 / 1.75 hr. /day @ $45 /hr	$16,425	$24,638	$28,744
Maintenance	$1,943	$2,921	$3,681
YEARLY OPERATING COSTS	$25,631	$41,301	$52,254
TOTAL COSTS ($/yr)			
Amortized Capital Costs (10 yr @11%)	$13,869	$20,856	$26,279
Operating Costs ($/yr)	$25,631	$41,301	$52,254
TOTAL YEARLY COSTS	$39,500	$62,157	$78,532
Cost per 1,000 liters	$1.97	$1.55	$1.30

TABLE F-7

Design Specifications for Recirculation and Irrigation

Capacity (liters/day)	55,000	110,000	165,000
Capacity (US gpm)	10	20	30
Leachate Storage			
Storage Cost ($)	$5,000	$7,500	$10,000
Distribution Pump & System			
Flow Required (gpm)	3	5	8
Pump & System Cost ($)	$5,000	$6,500	$7,500

TABLE F-8

Capital and Operating Costs for Recirculation and Irrigation

Capacity (liters/day)	55,000	110,000	165,000
Capacity (US gpm)	10	20	30
CAPITAL COSTS ($)			
Leachate Storage	$5,000	$7,500	$10,000
Distribution Pump & System	$5,000	$6,500	$7,500
Total Equipment Costs	$10,000	$14,000	$17,500
Installation Costs	$16,000	$22,400	$28,000
TOTAL CAPITAL COST	$26,000	$36,400	$45,500
OPERATING COSTS ($/yr)			
Labour .75 / 1 / 1.25 hr. /day @ $45 /hr	$12,319	$16,425	$20,531
Maintenance	$1,000	$1,400	$1,750
YEARLY OPERATING COSTS	$13,319	$17,825	$22,281
TOTAL COSTS ($/yr)			
Amortized Capital Costs (10 yr @11%)	$4,420	$6,188	$7,735
Operating Costs ($/yr)	$13,319	$17,825	$22,281
TOTAL YEARLY COSTS	$17,739	$24,013	$30,016
Cost per 1,000 liters	$0.88	$0.60	$0.50

TABLE F-9

Design Specifications for Rotating Biological Contactor

Capacity (liters/day)	55,000	110,000	165,000
Capacity (US gpm)	10	20	30
RBC Unit			
System to include: 1) Transfer Pump, 2) Clarifier, 3) interconnecting piping and 4) Meters and Controls			
Feed BOD Level (mg/L)	275	275	275
Surface Area of Media (sq. ft)	16,000	32,000	48,000
RBC System Cost ($)	$100,000	$135,000	$175,000

TABLE F-10

Capital and Operating Costs for Rotating Biological Contactor

Capacity (liters/day) Capacity (US gpm)	55,000 10	110,000 20	165,000 30
CAPITAL COSTS ($)			
RBC Unit	$100,000	$135,000	$175,000
Total Equipment Costs	$100,000	$135,000	$175,000
Installation Costs	$160,000	$216,000	$280,000
TOTAL CAPITAL COST	$260,000	$351,000	$455,000
OPERATING COSTS ($/yr)			
Labour 1.5 / 2 / 2.5 hr. /day @ $45 /hr	$24,638	$32,850	$41,063
Maintenance	$10,000	$13,500	$17,500
YEARLY OPERATING COSTS	$34,638	$46,350	$58,563
TOTAL COSTS ($/yr)			
Amortized Capital Costs (10 yr @11%)	$44,200	$59,670	$77,350
Operating Costs ($/yr)	$34,638	$46,350	$58,563
TOTAL YEARLY COSTS	$78,838	$106,020	$135,913
Cost per 1,000 liters	$3.93	$2.64	$2.26

TABLE F-11

COST BASIS FOR COMMODITIES

Lime ($/Kg)*	$0.10
Polymer ($/kg)	$6.00
Power ($/KW)	$0.06
Labour ($/hr)	$45.00

* Delivered Cost on a one metric tonne basis, 1990 $CDN.